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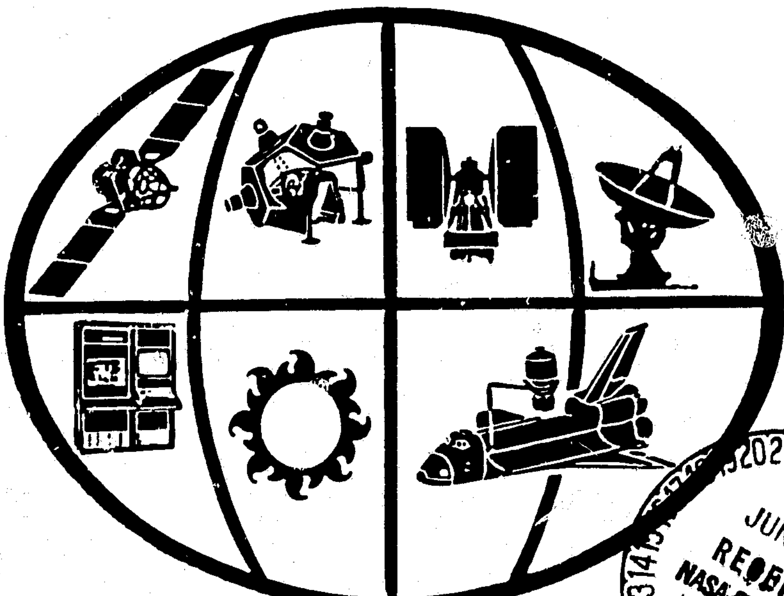
FINAL REPORT ON CONTRACT NAS8--32491 MOD 1

PREPARED FOR

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
MARSHALL SPACE FLIGHT CENTER HUNTSVILLE, ALABAMA



space division

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GENERAL ELECTRIC

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DATA SYSTEM IMPLICATIONS DERIVED FROM USER APPLICATION REQUIREMENTS FOR SATELLITE DATA

FINAL REPORT ON CONTRACT NAS8-32491 MOD 1

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1.0 INTRODUCTION

This report was prepared under contract to the National Aeronautics and Space Administration, George C. Marshall Space Flight Center (MSFC) as partial fulfillment of the requirements of Contract NAS8-32491, Mod 1. This report documents an investigation of the data system needs as driven by users of space acquired earth observation data. Specific data system issues for Global Crop Production Forecasting were excluded because they were addressed in other reports (References 1, 2, and 3).

2.0 OBJECTIVE

The objective of this study was to analyze major data system issues of the next decade from the viewpoint of the needs of users of space data. The intent of the study was to concentrate on significant factors that will influence the direction of the future NASA data system and to recommend implementation approaches that will benefit the use of space acquired data for studying, monitoring, and managing the earth's resources and environment.

3.0 SUMMARY, RESULTS, AND CONCLUSIONS

The approach of developing a set of data system requirements for users of space data based upon their needs is desirable but difficult. In this study, requirements suitable for performing trades on data system issues were developed. When compiling the necessary requirements, it became apparent that there is no authoritative set of users with a finite set of requirements. As a first step in this study, trade-offs of benefits, liklihood of commitment, required development, and cost of data products were performed on a subset of all possible users of space data. One result of this study is an identified set of users whose requirements typify the requirements of the 1980 to 1990 data system.

Additional conclusions as to the necessary attributes of the data system and the approach to implementing them resulted from analysis of the user requirements and their applications as well as current and planned programs and technology.

The user community is diverse in scientific discipline, degree of sophistication, data volumes used, resources available, and the needs for data products. Because of this great diversity in many dimensions, flexibility is a mandatory requirement to be levied against the data system.

There are two major categories of users, operational and research, with some incompatible requirements that are best served by a data system with segments dedicated to the needs of each group. This incompatibility of requirements was found throughout the analysis. The resulting trade-offs consistently showed that a single general purpose approach was not workable for performing those functions. The shared use of common resources is desirable when the requirements are compatible.

The majority of the currently conceived applications of space data can be met with current satellite and sensor technology. The planned satellite systems, if implemented, will provide adequate opportunities for acquiring the needed data. However, the current programs and systems for processing and delivering the needed information are inadequate in the following areas.

Data acquisition must be selective in the operational environment to prevent the collapse of the ground data handling system. The routine application of space data to operational programs will require frequent observations. For example, for agricultural needs alone, a data density of over 180,000 bits per square kilometer of ground measurement is required on the order of every two or three days. Planned satellite and sensor systems are capable of achieving this rate of acquisition, but the ground processing system is not capable of handling this quantity of data over a sustained period. A thirty day acquisition over agricultural land would amount to 2×10^{15} bits. Since the users do not require this total data volume, data should only be taken as justified by application requirements as opposed to system acquisition capability.

Data retention must also be limited in the operational environment. The cost of archiving data to guard against loss imposes too great a burden on the cost of the information delivered to operational users. Raw data should be retained for research and experimental uses only in reasonable volumes. For operational applications, the delivered information should be the driving parameter and the raw and intermediate data acquired or generated during the production of the delivered information should be discarded as soon as practical.

The system should perform a strong data management function. This includes the control of data acquisition, the retention of data, and the scheduling of system resources. It should extend to the allocation of blocks of time for such resources as pointable sensors to permit direct user interaction with the acquisition process.

In the operational end-to-end system an increased number of data processing functions should be performed as early as possible in the system data flow. It is more efficient to perform certain functions once and make the results available to all users rather than to require each user to duplicate the process. On board processing is desirable for the operational applications with the restriction that the system must be flexible enough to bypass certain operations a portion of the time to meet research requirements.

A new and sophisticated data distribution system is required. The diversity of users and their requirements and their geographic disbursement indicates the need for a sophisticated system. It should incorporate multiple media of data transportation that will be economical and flexible for high and low volumes with quick response when required. On line interactive information requests and some analysis capability are required. The system must reduce the total quantity of data stored, the amount of redundant processing required, and the overall response time to the users' requests. The system must also perform a user requirements management function that includes the allocation of resources such as processing facilities, communication links, and data taking capacity. Additional added value functions most efficiently performed by the system includes the establishment and maintenance of a collateral data base of ground truth, atmospheric absorption properties, and spectral signatures. The ability to correlate data from a multitude of sources as a system function will enhance application efficiency.

4.0 BACKGROUND

In February of 1962, a group of eighty scientists met on the campus of the University of Michigan to explore possible applications of remote sensing technology to various earth science fields. The participants at this first symposium of the Institute of Science and Technology were almost entirely members of the academic world. Seventeen years later the community interested in applications of remote sensing has become diverse, sophisticated, and widespread. The growing interest in remote sensing is demonstrated by the growth of that earlier symposium to the current Environmental Research Institute of Michigan, commonally called ERIM, symposium that in 1978 had over eight hundred attendees from throughout the world representing industry, government agencies, the scientific community, and commercial users.

The utility of remote sensing has been demonstrated in the application areas for better understanding our environment and for better management of both our renewable and non-renewable resources. In 1978, the President's Science and Technology advisor, Dr. Frank Press, asked the Intergovernmental Science, Engineering, and Technology Advisory Panel (ISETAP) to provide information and policy recommendations on remote sensing and specifically applications of Landsat from the perspective of state, local governments, and regional agencies. This report (reference 4) makes it perfectly clear that "Landsat is an important technology that is presently making and can continue to make significant, often unique contributions to the information base required for state and local government's management of natural resources." To paraphrase from this report, there are many applications where Landsat is the only feasible way of obtaining needed data because conventional techniques are too costly. They cite the repetitive coverage, the synoptic measurements, and the standardized data as significant benefits of data remotely sensed from space.

In 1978, there were 23 states using Landsat data because it is more cost effective than other means. Seven states have independent, ongoing operational analysis and application capability. Three of the seven were extensively using Landsat data in planning and managing their natural resources. Twelve states had completed demonstration projects, nine expected to complete a program soon and sixteen were in the early phases of demonstration projects. In all, in 1978, 35 states had some involvement in some of 157 different applications of Landsat data for planning and managing their natural resources.

The task force identified a need for a commitment by the federal government to provide operational data. Users want continuity of the data and continued compatibility of formats. They also identified timeliness as a crucial criterion, citing delays and uncertainty in obtaining the data from the ground system as the major impediments to further applications.

Scientists seeking a better understanding of our environment have a long history of using the latest technological achievements. The application of satellite remote sensing to weather monitoring and prediction typify a class of sophisticated users. Weather, being a global phenomena, is an application well suited to the synoptic measurements achievable from satellites. Some early applications for operational weather forecasting are discussed by Cooly (reference 5). As a result of two United Nations resolutions, two major programs have evolved, World Weather Watch and Global Atmospheric Research Program. The United States participation in these programs has had a significant impact on operational satellite data systems. The makeups of the Global Data Processing System for World Weather Watch is described by Zavos (reference 6). The importance of an operational worldwide system to other applications was demonstrated in the Large Area Crop Inventory Experiment (LACIE). As a result of LACIE, additional data was reported by the participants in the World Meteorological Organizations (reference 7).

The United States weather monitoring and forecasting is performed by the National Weather Service (NWS), a component of the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce. The NWS operates in a strict operational environment, exercising computer models of the atmosphere that yield results according to pre-established deadlines. Much of the data input to these models is provided by the National Environmental Satellite Service (NESS), another component of NOAA. These models, their inputs, their outputs, output timeliness and formats are described in a series of Technical Procedure Bulletins (reference 8).

Local television and radio stations use this information several times daily for disseminating local weather forecasts. The television viewers in the United States have become accustomed to seeing the accelerated motion cloud photos from the synchronous meteorological satellite. This and other

NOAA/NESS satellite data products are described in the GOES/SMS Users Guide and in a catalog of products (reference 9).

Users of oceanic data have previously lived with the sparse reports from ships in the shipping lanes or from an occasional research vessel. With the advent of satellite-sensed data, the entire ocean is accessible regularly and at nearly the same instant in time. It is estimated that SEASAT-A surface wind data is equivalent to 20,000 ship reports per day (reference 10). In 1962, John Glen reported he could distinguish the Gulf Stream from his vantage point in the Mercury Satellite. Also, in the early 60's the first meteorological satellite, TIROS I, transmitted pictures of ice in the Gulf of St. Lawrence within hours after it was launched (reference 11). These early applications of satellite-sensed data to oceanic phenomenon have spanned a multitude of uses and users. Some of the early uses are described by Zaitzeff and Sherman (reference 12), and Ewing (reference 13). A comparison of the uses discussed at these early conferences with uses discussed more recently such as at "Ocean 78" (reference 14) illustrates the increasing concern for the economics of applying remote sensing rather than the feasibility.

When the applications of remotely-sensed data are analyzed, it is apparent that the utility of the data is accepted by a large and diverse community of users. The space information system as a whole is currently in a transitional phase. Simultaneous with increasing commitments to use space acquired data because it is cheaper and does a better job, there are still ongoing efforts to establish better and more efficient ways of using the data. These conditions can be expected to coexist for some time in the future. Thus, the direction of the future data system is one that will simultaneously provide increased efficiency and timeliness of data in a quasi-operational sense, ultimately leading to a fully operational system. It must also respond to the specialized needs of the experimenter and the R&D community.

4.1 DATA SYSTEM ISSUES

Guidance for identifying major issues of the future data system is available from a brief look at the present system. The NASA End-to-End System (NEEDS) Study plan (reference 15), highlights some concerns with the present system.

"The present data management system is a complex arrangement of functions which has evolved on a problem-by-problem basis to meet the increased demands placed upon it by the changing nature of the space program. It consumes approximately 20 percent of NASA's resources, has certain limitations, and lacks consistency in organization and structure at the extremes of the system."

There is apparent agreement among both the users and the suppliers of space data that the future system will be different. What presents a challenge is to quantify the specific function, capabilities, and performance requirements for the future system. The evolving nature of the technology and the users make it difficult to obtain authoritative requirements based upon user needs. Traditionally, the users have learned to rely upon the information that is provided. The technologists have had more experience in forecasting what the users will use than have the users had in forecasting what the technologists will supply. In this study, an attempt was made to converge the requirements from both ends of the system, based upon an investigation of the basic science as it relates to both the technology and the applications.

Many investigations of space data application have been performed and many user identification studies have been reported. Additional studies have been funded by NASA to further define the data system requirements. In 1975, extensive work was performed on the program on Earth Observation Data Management System (reference 16). More recent studies, such as Total Earth Resource System for the Shuttle Era (TERSSE) (reference 17) and the Global Services Satellite Circa 1995 (reference 18), have projected future uses of satellite data assuming that an operational data system capable of meeting the requirements of those users will exist. The current concern for obtaining a valid set of semi-operational user requirements is emphasized by the U.S. Office of Management and Budget direction to NASA, DOD, and other departments to study the possibility of converging their individual requirements into a common set that can be more efficiently accommodated by a common data system.

4.2 CHARACTERISTICS OF USER COMMUNITY

The breakdown of user requirements resulting from the studies performed can be illustrated in the diagram of Figure 1. This grouping also accounts for the maturity of the applications. The first group of bonafide users were the government agencies responsible for monitoring the environment and managing our natural resources. These agencies were the first to have legal authority and funding to apply the results of remote sensing to perform their specific charter functions. In many instances, they were previously performing like functions and found it to be more economical to apply remote sensing to their problems.

For this discussion, it is desirable to identify potential users in the next decade and to identify bonafide data system requirements and issues pertaining to these users. The management group of users is significant because they currently meet the following conditions:

1. They will have a legitimate charter function involving either the monitoring or the management of either earth resources or the environment.

2. They will have an operating budget to perform that function, whether it be done using remote sensing or via some other means.

Government agencies, federal, state, local, and in some instances suprafederal, such as The United Nations, are the major users in this group. Users in this group comprise both those agencies established by the various governments to monitor conditions, establish regulations and to enforce compliance, as well as those agencies with a primary function of obtaining information either for advisory purposes or for purely scientific interests. This group of users also includes non-government organizations such as "not for profit" environmentalists. This group of users is significant because they are most likely to be the major near term users.

Group 2 consists of the scientific community. When identifying requirements for a data system serving users of remote-sensed data, it is essential to consider uses as well as users. Closely allied with uses are users in the scientific and university communities. This is the research and development or experimental areas and is the other major area of near term users. Almost

ALL ACTIVITIES RELATED TO THE ENVIRONMENT AND NATURAL RESOURCES
ARE POTENTIAL BENEFICIARIES OF REMOTELY SENSED DATA FROM SPACE.

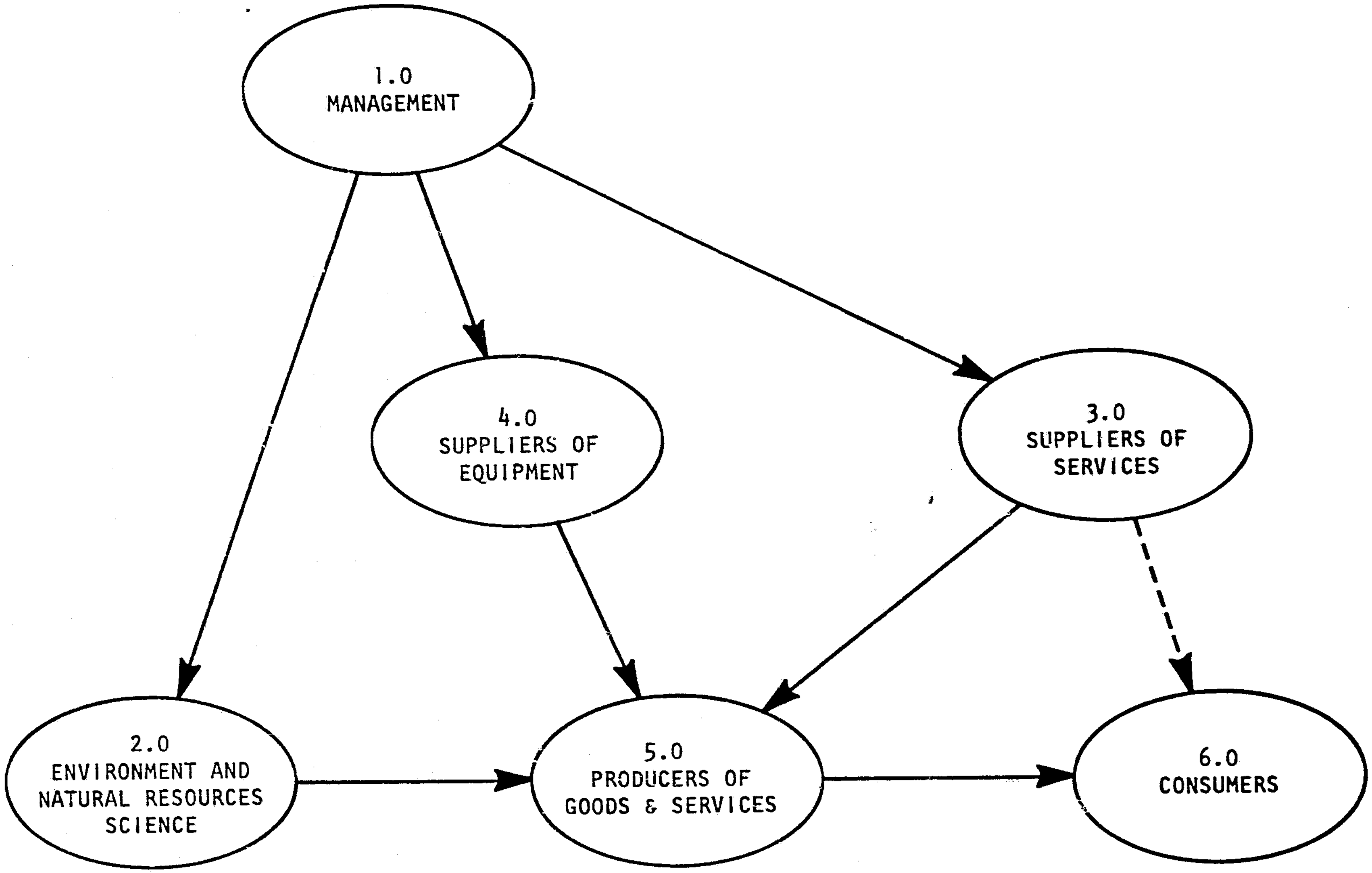

Figure 1. Activities Impacted By Remotely Sensed Data From Space

every user in the other groups are first represented by an experimental user in this group. A representative listing of uses is included in the appendix.

Continuing with the grouping of users according to the time phasing of uses is the group of suppliers of services. This group of users is not an end user in quite the same sense as the management group. This group presently has some large data users that are currently serviced by the present data systems. This group is important because the meeting of their requirements is critical for any data system. The predominant users in this group are the various branches of the Department of Defense, NOAA/NESS, and the Department of Agriculture. They are semi-end users in that they use the remote-sensed data to perfrom a service for the country as well as acquire the data and make it available for other users. Because of the importance of members of this group in driving the data system requirements, the Coast Guard and other services of NOAA such as the National Weather Service were considered part of the group although they would more logically be part of group 5. The justification for including these services in group 3 is they are currently end users of the space data. Group 5 is reserved for end users of space data that provide other goods and services as opposed to group 3 where the space data itself is part of the service provided. For this study, requirements of user groups 4 and 5 were not considered because of the far term implementation projection.

Another potential set of users in group 3 is the industry organizations and consortiums that may preprocess the space data for information useful to their members. Again, the criterion applies that the users are not end users of the data but the space data is inherent in the service provided.

The next group of users in the expected time phased application of space data is the suppliers of equipment. These industrial users are not end users of space data. They are akin to the R&D users of group 2 and their needs will be adequately met by a system meeting the needs of the first three groups.

Ultimately, space data will be applied by users in nearly all industries--individual commercial fisheries, agribusiness, etc. Oil and mining companies currently are using space data in a sense of users in groups 2 and 4. The requirements for this group of users were not considered as impacting the data system requirements during the time frame of this study. Likewise, the consumers as a group of space data users were not considered. There may be the occasional weekend boaters equipped with receiver gear to use space data directly but this is a small part of this group. While the consumer will benefit by better goods and services by the users of group 5, they are not considered as an influence on the requirements of the data system.

4.2.1 Uses Influencing Data System Requirements

The users of space data having a direct impact on the data system requirements fall into the first three groups previously described: Management, Suppliers of Services, and Environment and Natural Resources Science. Management and Suppliers of Services are operational users. Environment and Natural Resources Science are experimental users that eventually are represented by other users in the operational sense. For purposes of developing data system requirements, a breakdown of uses of the science users will serve for the other users. The special needs of the experimenter will be considered, but the major impact is seen by the operational needs. The breakout as established at the start of this study is still valid, with some minor modifications. The initial breakout was "Agriculture," representing the earth resource applications including land use and "Weather" representing environmental monitoring applications. There is a grey area of Ocean Monitoring that although starting as an environmental monitoring application, has developed many earth resources attributes. For consistency with the original plan, ocean monitoring will be considered in the "Weather" grouping.

4.2.2 Agricultural Trades

The significant factors affecting agricultural users of space data apply to other users with earth resources monitoring and management applications. A brief investigation of the needs for image data for agricultural application, how it will aid an agency with operational responsibility, a technical issue with controversial implications and the relationship to an application with diverse needs will typify the issues of meeting space data user needs.

The agricultural application of space data is centered with the U.S. Department of Agriculture. This agency has primary responsibility for establishing policies affecting price, marketing and consumption of agricultural products, establishing and advising programs to assure the adequate supply, to promote efficient production, etc. In this role, it is essential that an adequate knowledge of current and projected supply and demand of agricultural products be obtained in a timely manner. Toward this end, remote sensing provides a cost effective approach for obtaining worldwide, accurate, timely, and synoptic information. The end information can be broken into three distinct functions. One is an inventory of available products. This inventory includes many products, some with commercial value to U.S. farmers and others that are important in the food supply of large segments of the population. For example, a reduction in the potato crop of northern Europe might displace barley on the European market which in turn might impact the wheat imports from the U.S. which in turn might put pressure on the domestic soy bean market. Thus, it is necessary that regional information be obtained.

The interaction of a commodity such as agricultural products affects more than the Department of Agriculture. The requirement for shipping is of interest to the Department of Commerce. Payments for the movement of goods is of interest to Banking and Finance. Balance of payments and international relations is of interest to the State Department. The success of programs of aid to developing countries is of interest to congress and their various advisory committees. The Department of Treasury is interested in smuggling activities and the sources of certain agricultural products. The list of the government and non-government agencies that have a need for accurate inventory of agricultural products is almost endless.

For an adequate inventory of agricultural products, a worldwide data base of land use is required. The data must include the extent of each application, as well as something about the use such as what crops are usually found in the area, the planting and harvesting practices, soil maps, etc. At least one observation of the entire area each year is required to determine changes in the amount of land committed to agriculture. In addition, there is a need to determine specific crop plantings. It is generally accepted that a sampling approach can be taken for this part of the inventory problems. The number and frequency of the samples required has yet to be established and it is very likely that the exacting requirements will evolve over years of learning, calibration against other inventory methods on controlled regions, and the establishment of correlation among crops. The primary driver on the space data needs for inventory is that required to adequately identify or classify the crop species. The approach judged most likely to be implemented operationally will require multiple observations separated by three days at specific times according to the recognized planting dates. The data of Table 1 quantifies the data volume required for inventory and other agricultural functions. The detailed development of the data volumes is presented in the Appendix. From the collateral data, the likely crop species will be known. Based on the collateral data and the detection of emergence, the critical times can be identified. For estimating purposes, the following assumptions shown in Table 1 were made.

The first requirements for agricultural inventory is a total land use sample after snow melt and before emergence. In the northern temperate regions, after spring tilling is ideal because it will give a good measure of planting intentions. The importance of this observation is to provide a basis against which information may be extracted. Once the total plantings are established, inventories of some species may be determined by subtraction of alternate crop species as they are determined. The detection of desertification and the conversion of previous non-arable land to arable land are important because these factors have a significant influence on total agricultural production capacity. The other reason why this first observation is important is that the soils are a major contributor to the makeup of remotely sensed data. Knowledge of this background is essential to be able to extract information about the plant contribution to the signals sensed later in the growing season.

The next observation requirement is needed to determine plant emergence. A sampling approach will be suitable and the collateral data will permit a selection of the areas requiring the samples at a particular time. An excess number of samples at this stage will permit great flexibility later during the season. The time resolution of these acquisitions are less stringent than some of those later in the season. An estimate of once every seven (7) days will

Table 1. Observation Requirements (Agriculture)

OBSERVATION REQUIREMENT	TIME PERIOD	AREAL EXTENT (KM)2	TOTAL NUMBER OF OBSERVATIONS	PURPOSE	FREQUENCY OF REVISIT	ESTIMATED TOTAL NUMBER OF BITS PER YEAR
1	EARLY SPRING (Pre planting but after snow melt)	ENTIRE LAND AREA	1	ESTABLISH LAND USE, LIMITS ON AVAILABLE AGRICULTURAL AREAS AND SOIL BACKGROUND	ONCE DURING A 30 DAY PERIOD	678508×10^6
2	EARLY GROWING SEASON	SAMPLES OF AGRICULTURE AREAS - ROLLING SAMPLE ACCORDING TO LATITUDE	8	DETERMINE EMERGENCE	EVERY 7 DAYS	563625×10^6
3	MID GROWING SEASON ACCORDING TO CROP CALENDARS	SAMPLES ACCORDING TO ESTABLISHED PLANTING PRACTICES	20	DETECT ONSET OF FLOWERING	EVERY 3 DAYS FOR 15 DAY PERIOD AT 4 DISTINCT TIMES	588500×10^6
4	LATE GROWING SEASON PER CROP CALENDARS	SAMPLES ACCORDING TO PREVIOUSLY ACQUIRED DATA	20	DETERMINE MATURITY	EVERY 3 DAYS FOR 15 DAY PERIOD AT 4 DISTINCT TIMES	588500×10^6
5	POST HARVEST	SAMPLE PER PREVIOUSLY ACQUIRED DATA	5	VERIFY HARVEST AND CONFIRM CLASSIFICATION	EVERY 7 DAYS	92591×10^6
6	MID SEASON PER CALENDAR	SAMPLE PER ESTABLISHED PLANTING PRACTICES	13	DETERMINE SOIL MOISTURE AND STRESS	EVERY 7 DAYS FOR 3 MONTH PERIOD	50310×10^6
7	WINTER DORMANCY PERIOD	WINTER WHEAT AREA	4	DETECT FROST KILL	AS REQUIRED WHEN IDENTIFIED VIA OTHER MEANS	27500×10^6
8	THROUGHOUT THE GROWING SEASON	SAMPLE OF AGRICULTURAL AREA	4	MONITOR EPISODES AND WEATHER STRESS	AS REQUIRED WHEN IDENTIFIED VIA OTHER MEANS	603104×10^6

Table 1. Observation Requirements (Land Use, Weather, and Ocean Monitoring) (Continued)

OBSERVATION REQUIREMENT	TIME PERIOD	AREAL EXTENT (KM)2	TOTAL NUMBER OF OBSERVATIONS	PURPOSE	FREQUENCY OF REVISIT	ESTIMATED TOTAL NUMBER OF BITS PER YEAR
9	1 EACH SEASON	TOTAL LAND 148940540 AREA	4	GENERAL LAND USE	3 MONTHS	67519708×10^6**
10	NOT CRITICAL	TOTAL LAND 148940540 AREA	1	GEOLOGY	1 YEAR	2404231×10^6** 25241777×10^6
11	NOT CRITICAL	TOTAL LAND 148940540 AREA	1	CARTOGRAPHY	OVER 1 YEAR	5295663×10^6** 21182653×10^6
12	AS REQUIRED DRY SEASON	25% OF LAND AREA 37235135	12	RANGE MANAGEMENT	3 DAYS TO 1 YEAR	15645625×10^6** 17362578×10^6
13	CONTINUALLY	WHOLE EARTH 510074600	1460	NUMERICAL WEATHER FORECASTS	6 HOURS	21067079×10^6**
14	CONTINUALLY	NORTH AMERICA 24320100	1460	MESOSCALE WEATHER	6 HOURS	23996061×10^6**
15	CONTINUALLY AS REQUIRED	SAMPLES OF NORTH AMERICAN AND COAST 26752110	8760	SEVERE STORM WARNING	2 MINUTES	5933349×10^6**
16	GROWING SEASON	ESTIMATED WORLD AG. AREA 75000000	250	AGRICULTURE METEOROLOGY	1 HOUR TO 1 DAY	6532500×10^6**
17	CONTINUALLY	TOTAL OCEAN 361134060	1460	PHYSICAL OCEANOLOGY	6 HOURS	15645625×10^6** 17362578×10^6
18	CONTINUALLY	TOTAL OCEAN 361134060	1460	NAVIGATION & STORM WARNING	6 HOURS TO 3 DAYS	24276233×10^6** 24413657×10^6
19	CONTINUALLY	POLAR REGIONS	52	ICE MONITORING	1 WEEK	1793315×10^6** 3467715×10^6

**ADDITIONAL DATA ONLY

permit a sufficient precision to identify emergence, to establish the start of the crop calendar and with the collateral data, to identify probable crop species. For particular climate regions identifiable from collateral data, the period of observational requirement can be narrowed to about two months. Consequently, the requirement for an average total of 8 observations per region to determine plant species emergence.

Once the location of crops has been identified, the start of the crop calendars are known, and the likely plant species are hypothesized, the crop calendars can be used to direct data taking of specific samples to detect the onset of flowering for each species. Based on the assumption of no more than four significant probable plant species in a given sample, four distinct critical observation times can be estimated using crop calendars from the collateral data base. The start of the calendar was previously determined. Within each of these windows, an observation is required every three days. In a similar manner, observations every three days during four specific windows can be justified for determining crop species maturity. Each of these requirements account for twenty observations or a total of forty. In an operational system, there might be some samples requiring more and others less. These numbers are averages projected for quantification purposes. The precise times of flowering and maturity relative to emergence when combined with the collateral data are expected to provide an accurate means of classifying crop species in an operational system.

The progression of harvest as well as the start of harvest in particular fields provide additional confirmation of proper species classification and agricultural inventory. The observation requirements are less stringent than the previous ones. One observation every seven days over a five week period is adequate. The location of the five week period will vary according to the region and the probable classification of plant species previously established. No significance is attached to total number of observations because of the differing extent from the first whole land area requirement to samples for determining maturity. These observational requirements were taken into account when establishing the data volume of Table 1. While the confirmation of these observation requirements must await demonstration projects, they are deemed adequate for analysis of data system impacts.

The other major component of agricultural applications is yield. This involves the projection of production before harvest. The USDA Economics, Statistics and Cooperatives Services (ESCS) currently makes these production forecasts by a procedure of regularly updating projections of plantings and deviations from normal yields for reporting districts. A major factor in determining the deviation from the normal is the weather conditions. Episodes also have a significant influence on production estimates, especially in the world statistics. The Foreign Agricultural Service (FAS) is currently responsible for these assessments. The requirements for space data to determine yield have not been established, but they can be estimated. They fall into three categories, image data, weather forecast, and precipitation. The image data requirements are expected to be met by the data acquired for meeting the inventory functions. The exact sample location may be different but it is likely that samples chosen for yield will also be adequate for the inventory. No additional data requirement is projected in Table 1. Weather data is of a long term forecast type and is not directly space related. No special weather data considerations were projected for yield. Precipitation data is the significant driver on the need for non-image data. A spatial resolution of 12.5 km square cells is projected based on a consideration of needed granularity to match soil types as well as availability of precipitation data. Soil maps are expected to be developed to a much finer spatial resolution in the collateral data base. For a practical limitation in the operational data base, the 12.5 km cell size grid spacing will be acceptable to precipitation data as the best workable interpolated resolution compatible with the collateral data of soil maps and planting practices.

There is a third requirement for space data that follows from the function of predicting deviations in yield from normal. This application of space data is currently being implemented in a limited manner by the FAS for early warning of disasters adversly affecting crop production in foreign countries. The quantification of data required for this early warning is difficult because it is a random function. It is best estimated as a fixed percentage of the other requirements. Both image data and meteorological data are required. Meteorological data includes temperature extremes, snow cover, and storms. The image data is similar to that needed for inventory and consists of multispectral visible, near and thermal infrared, and possibly microwave bands.

4.2.3 Land Use

Other natural resources management functions are adequately represented by land use. Some of the major ones are water availability, geology, cartography, and range management. These uses are considered as indicatvie of special requirements over and above a specific consideration, in this case agriculture, that can have conflicting influence on data system requirements. Major considerations are indicated in Table 2.

A brief analysis of Table 2 which compares four applications of similar space data as needed by agriculture indicates a conflict in requirements. Generally, the application that is a driver in one parameter, such as precision of location, total quantity of data, frequency of revisit, or maximum tolerable transit time has relaxed requirements in other parameters. This leads to the conclusion that the data system serving these users should be flexible enough to permit a trade-off of performance parameters during operations. It is not necessary to serve each user with the same data or data products. An example of such an operation is a sensor system that can scan wall to wall or that can take repeated measurements in one portion of the total field of view. At any particular time, data can be acquired for either land use or agriculture, yet the total system will not have to handle the data volumes indicated by a simultaneous performance to the summation of the requirements.

4.2.4 Environmental Monitoring Use

Two applications areas were used to represent environmental monitoring requirements: weather, and ocean monitoring. The weather users represent the sophisticated user with established operational requirements. Ocean monitoring users represent a different category of users with diverse requirements. The users primarily are researches with a background in ocean science. They are accustomed to working with a sparse amount of data and are grateful for the synoptic data available form space. With few exceptions, the requirements for operational applications have not been defined. For those that have, the users of the space data are providing a service to other end users. The conflicts in driving parameters exhibited in the earth resources management area are also exhibited by weather and ocean monitoring applications. Significant differences are portrayed in Table 3.

Table 2. Comparison of the Land Use Requirements with Agriculture

OTHER USE	SIGNIFICANT NEED	AGRICULTURE NEED
GENERAL LAND USE	oWALL TO WALL SAMPLING oNOT TIME CRITICAL oMULTIYEAR UPDATE oOBSERVATIONS DURING DIFFERENT SEASONS	oSAMPLES MORE DESIRABLE oIS TIME CRITICAL oUPDATES SOMETIME NEEDED WITHIN 3 DAYS oOBSERVATIONS NEEDED DURING GROWING SEASONS
GEOLOGY	oTOTAL LAND OF INTEREST oEARLY MORNING OBSERVATIONS oSPECIFIC SPECTRAL BANDS DESIRED oSHADOWS USEFUL	oARABLE LAND ONLY oMID DAY OBSERVATIONS oDIFFERENT BANDS DESIRED oUTILITY OF SHADOWS NOT DEVELOPED
CARTOGRAPHY	oPRECISION OF SPATIAL FIDELITY IMPORTANT	oSPECTRAL FIDELITY MORE IMPORTANT
RANGE MANAGEMENT	oTEMPORAL RESOLUTION DEPENDENT UPON WEATHER CONDITIONS oRAPID SYSTEM RESPONSE TO INFORMATION	oTEMPORAL RESOLUTION DEPENDENT UPON CROP CALENDARS oSLOW SYSTEM RESPONSE TO INFORMATION

Table 3. Comparison of Ocean Monitoring Requirements with Weather

OTHER USE	SIGNIFICANT NEED	WEATHER NEED
PHYSICAL OCEANOGRAPHY	oREFLECTION COEFFICIENTS OVER OCEAN	oREFLECTION COEFFICIENTS OVER BOTH LAND AND SEA IN HEMISPHERE OF INTEREST
	oRETENTION OF DATA FOR TREND ANALYSIS	oRESULTING INFORMATION IN 6 HOURS WITH NO OPERATIONAL NEED FOR HISTORICAL RAW DATA
	oHIGH SPATIAL RESOLUTION TO DETECT ISOLATED LOCAL DIFFERENCE (1 KM)	oINTEGRATED RESOLUTION TO MATCH MODEL GRANULARITY, TYPICALLY 100 KM
ICE PACK MONITORING	oHIGH SPATIAL RESOLUTION TO DETECT OPEN WATER (120 METERS)	oNO NEED FOR SUCH HIGH SPATIAL RESOLUTION
	oFREQUENT UPDATE ON PACK ICE MOVEMENT (8 HOURS)	oUPDATE ON CHANGE IN TOTAL ICE CONDITION (WEEKLY)
	oTEMPERATURE OF INTEREST NEAR FREEZING POINT	oENTIRE TEMPERATURE RANGE OF INTEREST
	oPRESENT LOCATION OF EACH ICEBERG IN SHIPPING LANES	oNO INTEREST IN ISOLATED ICEBERG
COASTAL ZONE	oVISIBLE SPECTRA AT HIGH RESOLUTION	oLITTLE OPERATIONAL INTEREST
	oSEA STATE AT GALE CONDITIONS	oSEA STATE OVER ENTIRE RANGE
	oSHORT TERM FLUCTUATION IN CURRENTS AS THEY EFFECT POLLUTANT DISPERSEMENT	oLONG TERM CURRENT CHANGES

4.3 CHARACTERISTICS OF PLANNED SATELLITE SYSTEMS

The planning and implementation of satellite programs is a very dynamic process continually affected by the realities of political pressures, budgetary restrictions, and occasionally by programmatic success or failure. The intent of this discussion is to characterize the type of earth observation satellite programs that can be expected during the next decade. The near term programs are being officially planned and budgeted. The farther out programs, generally past 1985, are in prebudget planning stages or are concepts that are generally agreed upon as desirable but are still subject to competition among other program approaches to providing the same information.

4.3.1 Earth Observation Program

The following breakdown of earth observation programs is arbitrary, but suitable for this study:

1. Shuttle Flights
2. Earth Resources Management
3. Environmental Monitoring
4. Platforms

The above breakdown illustrates the transitional decade in space applications. Shuttle flights will begin in 1980 and will provide many repeated opportunities for sensor development and experimental application of space data to both the earth resources management and the environmental monitoring areas. These programs are mentioned for completeness of the categories and do not form the basis of this study except as this capability influences the trade-offs involving the facility of accomplishing necessary precedent experiments and acquiring special collateral data.

The Earth Resources Management programs are exemplified by the Landsat and the Stereosat programs. The currently operating Landsat 3 and the Landsat D scheduled for launch in 1981 are quasi-operational. They carry multispectral visible and infrared scanning sensors in low earth orbit, regularly providing images with ground resolution on the order of tens of meters and revisit opportunities on the order of every two weeks. A transition from this quasi-operational to operational system is planned in the Operational Earth Resources System (OERS) (reference 19). The emphasis here is on the word system since the planning involves multiple satellites of different sensor compliments. As currently planned, there will be two optical satellites (probably refurbished Landsat D's) and a soil moisture mission satellite with a multifrequency microwave radiometer. The expected time phasing of these and other missions are shown in Figure 2. The significance of the OERS is its intended application for multiple earth resources disciplines, agriculture being only one.

Another future satellite is the Stereosat. This system is interesting because of its genesis in industry. A consortium of users, especially geological industries such as oil and mining companies, are actively lobbying for this system with the express purpose of providing a vehicle for industrial funding and involvement.

Satellite systems in the Environmental Observation Area can be grouped into three categories: NOAA/NESS, NOSS, and AEM. The NOAA/NESS satellites form the only current operational non-military satellite system. The system comprises the three high altitude satellites in geostationary equatorial orbit, SMS/GOES, and the low earth orbiting (LEO) NOAA series of polar orbiters. These are familiar as the TIROS series. In addition to this operational set of satellites that primarily serve the weather and climate disciplines, but also provide information useful to oceanology, the NIMBUS series serves as the experimental platforms for future sensor systems.

The operational weather and climate satellites will continue. Supplemental environmental data will be available from other satellites with specific missions such as Oceansat, Ocean Circulation Satellite, and Icesat. A transition to quasi-operational systems is also expected with these ocean missions. The National Oceanic Satellite System (NOSS) (reference 20) will incorporate Oceansat and possibly other missions for combined scientific data collection and data collection for specific operational applications.

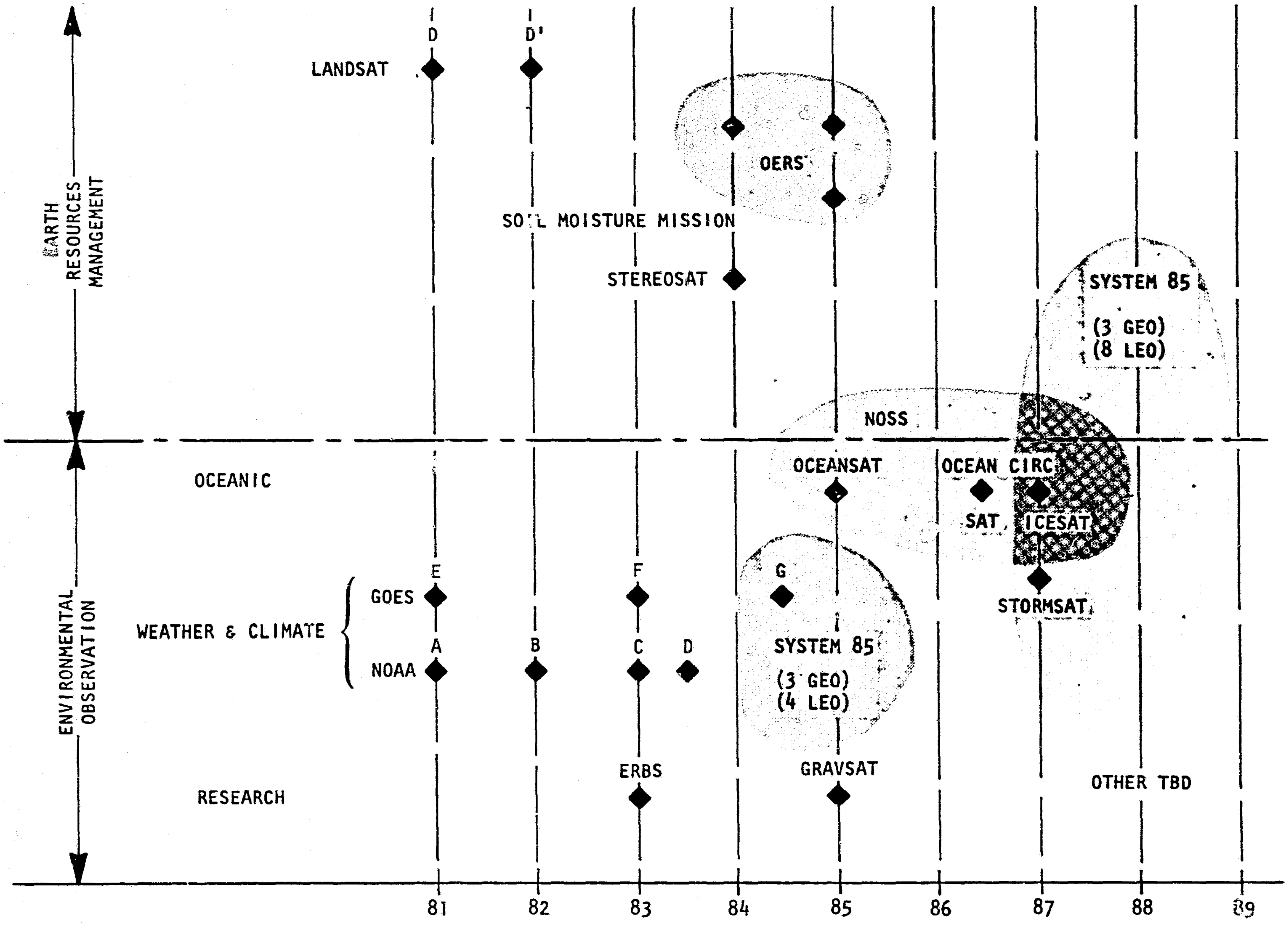

Figure 2. Future Earth Observation Satellite Systems

The other series of satellite systems primarily serving environmental observation applications is the Application Experiment Modules (AEM). They are just as the name implies which is experimental. Magnetic Mapping Mission (MMM), Upper Atmospheric Research Satellite (UARS) and Gravsat are some of the identified satellites of this type. These are the type of satellites that will still retain much of the one to one relationship between the principal investigator and the sensor design and mission planning. Nevertheless, the data acquired by these missions will be integrated into the total information available for performing other applications.

Toward the latter half of the next decade, the platform concept of space systems will be employed. This concept considers a point in space as a resource to be shared among many applications. Satellites in orbits designed for nearly optimal coverage for all applications provide platforms for many different sensors. The sensors will be activated according to the needs of the specific application programs. The platforms approach melds the earth resources management and the environmental observation programs, at least for the operational systems. System 85 as described by Atlas et al (references 21 and 22) will consist of three GEO's and eight LEO's. This system will provide a three-hour revisit opportunity for weather measurements. Since this system is still in the conceptual stages, the time phasing, the makeup of the sensor compliment, and the number of satellites cannot be accurately predicted. It will probably be an accretion of in orbit systems such as the NOAA/NESS and NOSS satellites. As the lifetimes of the early satellites in those various programs run out, the replacement satellite will be bigger, more capable and more general purpose until a true platform system evolves.

4.3.2 Sensor Systems

All the sensors that can fly on satellites will conform to certain principles unless there is some unforeseen breakthrough in the laws of physics. Even that would not effect the operational sensors that will fly in the next decade. With the exception of in situ measurements in which the satellites act as communication relays, the data will be sensed remotely, which limits the methods of detecting disturbances in electromagnetic energy, fields, or particle counts. Gravity gradient sensors and magnetometers sense disturbances of fields. Existing sensors of these types are now flying. The Space

Environmental Monitor (SEM) subsystem or the GOES/SMS system currently includes a magnetometer and an energetic particle monitor. Any future developments will consist of refinements in sensitivity and precision. The majority of earth observations remote sensors detect disturbances in electromagnetic waves. Each is sensitive to specific bands that are usually categorized: ultraviolet, visible, near infrared, thermal infrared, and microwave. The ultraviolet region is not significant for earth observation sensing primarily because most of the ultraviolet illumination is absorbed in the atmosphere. Some sensors are termed active, especially in the microwave region, in principal supplying the excitation or illumination energy. Some of these such as the radar altimeter just sense the presence and timing of return signals. Others such as some Mie scattering pollution detectors measure the shifts in the return signal strength due to particles of measurable size or the absorption of energy in narrow bands. Examples of existing sensors for each of the electromagnetic regions of interest and typical ground spatial resolutions are presented in Table 4. The sensor systems in this table are presently existing and the data from them was used to demonstrate the various planned applications. The argument presented is that for every application identified, there already exists a sensor system to acquire the data. Particular applications may require specific resolution or spectral responses, but that will be within the available technology.

4.3.3 Data Availability

With the observational opportunities afforded by the planned system, the revisit times required by the users can be met. From the sensor technology standpoint, the sensitivities required can also be met. Critical problems arise from timeliness and cost considerations that are directly related to the total data volumes and data processing systems.

5.0 KEY ISSUES TRADE-OFFS

During this study, trade-offs were analyzed in the areas of five key issues. They were:

1. Timeliness
2. Data Acquisition
3. Data Processing

Table 4. Typical Sensor Systems

ELECTROMAGNETIC REGION	REPRESENTATIVE SENSOR & FLIGHT PROGRAM	SPECTRAL BANDS	SPATIAL RESOLUTION	PROBABLE EVOLUTION
VISIBLE	THEMATIC MAPPER LANDSAT D	4	30 METERS	REPLACE MECHANICAL SCAN WITH LINEAR ARRAY 15 METER RESOLUTION FOR SMALL AREAS
NEAR INFRARED	VERY HIGH RESOLUTION SPIN SCAN RADIOMETER NIMBUS	3	10 KM	INCREASED RESOLUTION TO .5 KM
	THEMATIC MAPPER LANDSAT D	2	40 METER	LINEAR ARRAY WITH DETECTORS OPERATING IN PHOTOVOLTAIC MODE
THERMAL INFRARED	VERY HIGH RESOLUTION SPIN SCAN RADIOMETER NIMBUS	2	50 KM	INCREASED RESOLUTION TO 1 KM
	THEMATIC MAPPER LANDSAT D	1	120 METER	LINEAR ARRAY WITH DETECTORS OPERATING IN PHOTOVOLTAIC MODE
MICROWAVE	SCANNING MULTIFREQUENCY MICROWAVE RADIOMETER NIMBUS	6	30 KM	INCREASED RESOLUTION TO 10 KM, SMALL AREAS TO 1 KM
	ATMOSPHERIC SOUNDER NOAA	2	30 KM	MULTIPLE CHANNELS INCREASED RESOLUTION TO 10 KM
	SCATTEROMETER	1	30 KM	INCREASED RESOLUTION TO 10 KM
	RADAR	1	10 KM	INCREASED RESOLUTION TO .1 KM
	RADAR ALTIMETER	1	N/A	INCREASED VERTICLE PRECISION TO SUB METER RANGE

4. Data Storage

5. Data Distribution

The questions analyzed for timeliness were:

1. What timeliness criteria is needed?

2. What timeliness degradations can be tolerated?

3. What application can be sacrificed to meet the critical timeliness criteria?

4. What bottlenecks in the system can be ameliorated?

5. What problems are merely symptomatic in timeliness?

During the evaluation, system bottlenecks and other problems affecting timeliness were analyzed. The issues investigated are listed in Table 5.

Table 5. Issues Subject to Trade-Off Analysis

KEY ISSUE	QUESTIONS ANALYZED
TIMELINESS	WHAT TIMELINESS CRITERIA IS NEEDED? WHAT TIMELINESS DEGRADATIONS CAN BE TOLERATED? WHAT APPLICATION CAN BE SACRIFICED TO MEET THE CRITICAL TIMELINESS CRITERIA? WHAT BOTTLENECKS IN THE SYSTEM CAN BE AMELIORATED? WHAT PROBLEMS ARE MERELY SYMPTOMATIC IN TIMELINESS?
DATA ACQUISITION	ARE THE PLANNED SATELLITE SYSTEMS ADEQUATE? ARE THE PLANNED SENSOR SYSTEM ADEQUATE? WHAT CAN BE DONE IN THE AREA OF DATA ACQUISITION TO BETTER MEET THE USES NEEDS? WHAT PROBLEMS IN DATA ACQUISITION NEED TO BE ADDRESSED?
DATA PROCESSING	HOW MUCH PROCESSING SHOULD BE DONE ON-BOARD THE SPACECRAFT? WHAT PROBLEMS ARE INVOLVED WITH ON-BOARD PROCESSING? WHAT PROCESSING MUST BE DONE BEFORE A USER CAN APPLY THE DATA? WHERE IS IT MOST COST EFFECTIVE TO DO THIS PROCESSING?
DATA STORAGE	WHAT DATA SHOULD BE RETAINED? HOW LONG SHOULD IT BE KEPT? IN WHAT FORM SHOULD IT BE STORED? WHERE SHOULD IT BE STORED?
DATA DISTRIBUTION	WHAT OPTIONS ARE THERE FOR DISTRIBUTING THE DATA TO THE USER? HOW DO THESE OPTIONS COMPARE WITH THE USER NEEDS? WHAT APPROACH IS MOST COST EFFECTIVE?

5.1 TIMELINESS

Space acquired data has a utility for many applications because it does provide a rapid means of data collection. Without the possibility of rapid collection, the applications would not have been considered in the first place. Consequently, for these applications, the data is perishable. These applications have promulgated a requirement for quick delivery of data products to the users. This requirement has given rise to the issue of timeliness. There is a relationship between the capacity of the data system required, and its cost, and the timeliness requirement that can be met. However, an analysis of the various applications as to their timeliness requirement reveals that most of those applications with a need for short delivery time have other ameliorating requirements such as not requiring large data volumes or having an infrequent need for the data. Representative applications in agriculture, land use, weather, and ocean monitoring are listed in Table 6 according to their timeliness requirement.

A study of the timeliness requirements will permit a tradeoff in the percentage of applications that can be served according to a predesignated confidence. The data system can be designed to meet the data volumes and timeliness on the presumption that the utilization will follow a normal distribution. By prioritizing the application, the critical function can always be met with infrequent delays in the less critical function. For selected applications such as some of the meteorological data collection, dedicated data system elements can be justified.

5.2 DATA ACQUISITION

The issue of data acquisition was raised in earlier studies (references 1 and 2). The issue is that only a small percentage of the acquired data is ultimately used for the final information extraction. In the referenced studies, it was found to be less than 0.05 percent for agricultural inventory. For an operational system, this .05 percent of the acquired data would have to bear the cost of acquiring and processing the other 99.95 percent as overhead. If the data system must be sized to acquire data with such large overhead, the investment cost will be unreasonably high and the resulting amortized data costs to the users will be so high as to inhibit many otherwise cost effective applications.

Table 6. Timeliness Requirements

TIMELINESS CATEGORY	REPRESENTATIVE APPLICATIONS	MOLLIFYING CONDITIONS
REAL TIME (LESS THAN 2 MINUTES)	oMETEOROLOGICAL DATA FOR NOWCASTING (DEWPOINT, WIND, PRESSURE, SKY COVER, VISIBILITY)	oREGIONAL; OPERATIONAL REQUIREMENT THAT CAN JUSTIFY REQUIRED COMMUNICATIONS
	oRADAR STORM DETECTION, SEVERITY, AND TRACKING	oSMALL AREA; INFREQUENT
NEAR REAL TIME (2-10 MINUTES)	oWEATHER PATTERN TRACKING	oOPERATIONAL REQUIREMENT THAT CAN JUSTIFY REQUIRED COMMUNICATIONS
NEAR REAL TIME (LESS THAN 1 HOUR)	oOIL SLICK DETECTION FOR SEARCH AND RESCUE	oSMALL AREA; INFREQUENT
	oCURRENTS AND SEA STATE FOR SEARCH AND RESCUE	
	oNUMERICAL METEOROLOGICAL DATA (INPUTS TO MODELS - VTPR, HUMIDITY, WIND VELOCITY)	oOPERATIONAL REQUIREMENT THAT CAN JUSTIFY REQUIRED COMMUNICATIONS
NEAR REAL TIME (1-4 HOURS)	oCOASTAL ZONE HAZARD PREDICTION	oINFREQUENT
	oOIL DETECTION FOR OCEAN POLLUTION ABATEMENT	
NEAR REAL TIME (4-6 HOURS)	oSEA STATE FORECASTS FOR SHIPPING, OFFSHORE RIGS, ETC.	oSPATIAL RESOLUTION NOT DEMANDING
	oSEA SURFACE DATA (TEMP, SALINITY, WAVE HEIGHT, WIND VELOCITY, WATER VAPOR, SURFACE ATMOSPHERE) FOR MEASUREMENT CORRELATION.	oAREA LIMITED TO OCEANS AROUND U.S.
NEAR REAL TIME (6-8 HOURS)	oFIRE SUSCEPTIBILITY	oSMALL AREAS - LIMITED TIME PERIODS DURING DRY SEASON

Table 6. Timeliness Requirements (Continued)

TIMELINESS CATEGORY	REPRESENTATIVE APPLICATIONS	MOLLIFYING CONDITIONS
NEAR REAL TIME (8-24 HOURS)	oFOREST CONDITION MONITORING	oSMALL AREA ON DEMAND
	oFLOOD RESCUE OPERATIONS	oSMALL AREA; INFREQUENT
	oRIVER RUN-OFF EFFECT ON FAST ICE	oSMALL AREA; INFREQUENT
	oBATHYMETRY - TRANSPORT FROM STORM SURGES	oSMALL AREA; INFREQUENT
	oSEA ICE CONDITIONS oICEBERG WARNINGS	oLIMITED AREA - EITHER ICE PACKS, POLAR REGIONS, OR SHIPPING LANES
	oSHIP NAVIGATION THROUGH ICE FIELDS	
	oMAP SURFACE WINDS FOR ICE MOVEMENT FORECASTS	
	oUPWELLING IN OCEAN FOR FISH LOCATION	oLIMITED AREA NEAR SHORE
1-2 DAYS	oEPISODE DAMAGE TO CROPS, RANGELAND, FORESTS, AND AREAS OF HUMAN HABITAT DETECTION AND ASSESSMENT.	oLIMITED FREQUENCY AND AREA
	oSEA ICE MAPPING	
	oCOASTAL WATER CHLOROPHYLLE AND OTHER MATERIAL MAPPING	oRESEARCH ACTIVITY - LIMITED AREA
	oTEMPERATURE TO MOISTURE DEPLETION CORRELATION	oRESEARCH ACTIVITY - LIMITED AREA
	oAGRICULTURE FREEZE DAMAGE ASSESSMENT	
	oSOIL MOISTURE ASSESSMENT	oSPATIAL RESOLUTION NOT AS STRINGENT AS FOR VISIBLE IMAGE DATA
	oFLOOD RECOVERY OPERATIONS	
	oIRRIGATION SCHEDULING	
2-3 DAYS	oRANGELAND DAMAGE ASSESSMENT	
	oPLANTING DATE ADVISORY (SOIL TEMPERATURE)	oSPATIAL RESOLUTION ABOUT 500 M^2
	oMAP PLAYAS LAKES	
	oSNOW AND ICE SURVEY oILLEGAL SURFACE MINING	oTIMELINESS CRITICAL ONLY DURING SNOW MELT PERIOD
	oSALINITY RESEARCH	oLIMITED TO SUSCEPTIBLE AREAS
	oAGRICULTURE SOIL MOISTURE MEASUREMENTS	oSMALL AREA NEAR SHORE
	oCROP CONDITION AND STRESS ASSESSMENT	
	oWEED ENCROACHMENT	
	oINSECT AND DISEASE MONITORING AND ASSESSMENT (SAMPLE AREA ONLY)	

Table 6. Timeliness Requirements (Continued)

TIMELINESS CATEGORY	REPRESENTATIVE APPLICATIONS	MOLLIFYING CONDITIONS
3-5 DAYS	oAGRICULTURE PRECIPITATION DATA oCROP PHENOLOGY MONITORING	oRESEARCH ACTIVITY NOT REQUIRING SIMULTANEOUS COVERAGE OF ENTIRE COUNTRY
1 WEEK	oCROP TYPE AND ACREAGE DETERMINATION oYIELD AND PRODUCTION FORECASTING oCULTURAL PRACTICES MONITORING oNUTRIENT DEFICIENCY AND SOIL PROBLEM MAPPING oMONITOR RANGE CONDITIONS oFORAGE AND LIVESTOCK MANAGEMENT oICE STABILITY FOR PLATFORM USE	
1-2 WEEKS	oGLACIER AND CLIMATE STUDY oMARINE LIFE MONITORING oOCEAN CURRENT MAPPING oOCEAN TEMPERATURE MAPPING oOIL AND MINERAL EXPLORATION oOIL SEAPAGE DETECTION IN OCEAN oSOIL MOISTURE MODEL DEVELOPMENT	
2-4 WEEKS	oFOREST REVEGETATION MONITORING oRANGE AND FORAGE PRODUCTION INVENTORY oACQUIRE DATA FOR RANGELAND LEGISLATION AND MANAGEMENT oMAP SURFACE WATER oMAP RIVER BASIN LAND COVER oWATER QUALITY AND LAKE HYDROLOGY RESEARCH oCHANGES IN LANDFORM MAPPING oOBTAIN SEA STATE STATISTICS FOR ENGINEERING USE	

Table 6. Timeliness Requirements (Continued)

TIMELINESS CATEGORY	REPRESENTATIVE APPLICATIONS	MOLLIFYING CONDITIONS
1-2 MONTHS	oSOIL CLASSIFICATION oSOIL EROSION ASSESSMENT oLINEAMENT MAPPING oROCK TYPE MAPPING oLAND FORM MAPPING oTHERMAL INERTIA MAPPING	
6-12 MONTHS	oINTERPLATE MOTION AND STRESS FIELDS oFOREST INVENTORY oFOREST SITE POTENTIAL DETERMINATION oFOREST STAND EVALUATION oFOREST AND WETLAND WILD LIFE HABITAT EVALUATION oRANGE RESOURCES SURVEY oRANGELAND REHABILITATION MONITORING oRANGELAND ERROSION MONITORING oMONITOR EFFICACY OF FIRE CONTROL PROGRAMS oDETERMINE LONG TERM CLIMATE EFFECTS ON RANGELAND oRIVER BASIN AND WATERSHED PHYSIOGRAPHY MAPPING oMONITOR EFFICACY OF AGRICULTURE PROGRAMS	

The obvious solution would appear to only take the 0.05 percent of the data that is required. However, therein lies the issue in that there is little experience available to guide the selection of the 0.05 percent or whatever the percent may be for other applications. The historical mode for data acquisition from space is to acquire data at the capacity of the sensor system and let the users extract the data they need from the large volumes available. This philosophy is incompatible with operational requirements as the following exercise will illustrate.

The multispectral scanner acquires data in the visible and near infrared region at a burst rate of about 3.3×10^{12} bits per day. Operational constraints such as operating in daylight only, while over land, and within available power budgets limits the total daily acquisition to much less than one-hundredth of that amount. Yet, some of the operational applications require a revisit time of 3 days. If the same approach were to be followed for the future operational data acquisition as is currently followed, that is take all the data in what is called a wall to wall sample over the entire swath of the sensor, a three-day revisit requirement for an MSS would acquire data at the rate of 10^{15} bits per year. If the Thematic Mapper with its additional bands, quantization levels, and spatial resolution were operated in this mode, the data would be acquired at the rate of 10^{17} bits per year. The existing data system has a capacity of accepting about 10^{13} bits of image data per year.

Since no users need or can possibly handle data volumes of the magnitude projected by sensor capacity, the issue of data acquisition involved finding the approach to acquire only the data actually needed. This task is made difficult because for some applications, the users don't know what data is needed. Frequently in the research group, the proper data set is selected only after many unsuccessful operations on the wrong data sets. Thus, if research effort is to continue, a certain amount of data must be taken just because it can be taken without a strict adherence to a policy of justifying it for a particular application.

In an attempt to quantify a reasonable data acquisition approach, driver applications areas were chosen for both earth resources management and for environmental monitoring. The significant data needs in each area are listed in Table 7. The operational needs may be contrasted with the research needs for each application. By the time the operational application is sufficiently developed to require the data according to specified parameters such as type, band, spatial, spectral, temporal resolution, or timeliness, the data need will also be sufficiently identified that only that data need be acquired. This leads to the suggestion of either pointing a sensor or extracting the desired data at the sensor. The trade-off on limiting data acquisition by this approach is that the many applications of the same type data may need it from different locations or at different times. It is also desirable to use each piece of equipment, such as the satellite, sensor system, and processing system to the fullest extent possible for as many applications as possible.

In contrast to the operational user, who has tough data acquisition requirements, but also can identify the data needs, the research user wants a little of everything. Generally, the researcher does not have need for the global extent of the operational uses. Data from representative areas is usually sufficient.

The researcher usually segments his investigation to a particular interest. If daily observations are required, it is in some few small areas. If global synoptic observations are required, the spatial resolution requirement is usually relaxed. Most researchers cannot handle large data volumes so they design their experiments accordingly. The resultant impact of research applications on data acquisition is that there should be some limited amount of data taken to provide a representative data base of space data. If the data system is sized to acquire complete global coverage to the maximum capability of each sensor type once per year with some selected multiple observations and some flexibility in the acquisition schedules to accommodate specific experiments, the research users' requirements will be met.

Table 7. Data Acquisition Drivers

APPLICATION AREA	OPERATIONAL	RESEARCH
Agriculture	High resolution samples with frequent revisits at critical times	Complete data on representative limited areas plus the ability to interact with data acquisition process in real-time.
Land Use	Total earth coverage with good geometric precision	Limited volumes of all types of data plus the ability to interact with data acquisition process in real-time.
Weather	Continual Synoptic Data	Historical data representative of many conditions plus the ability to interact with data acquisition process in real-time.
Ocean Monitoring	Requirements evolving with the need for specific details in limited areas developing as ocean models are developed.	Complete data on representative limited areas plus the ability to interact with data acquisition process in real-time.

An additional data acquisition function that is desired by the researchers and is a solution for operational requirements is the ability for the user to interact in real-time with the data acquistion process. The space resources can be time-shared much as computational facilities now are. The space resources may be prescheduled in fixed blocks as well as a certain amount of "open" time available on a first come, first served basis. This resource sharing can accommodate several levels. Obviously, less pertubation should be permitted in orbit variation than in compression algorithm. The former requiring long time to effect while the latter could be accommodated in real time almost transparent to another waiting user.

For a platform with limited housekeeping resources, such as power, sun pointing, and communication links, there might be a sharing of these resources among sensors according to pre-established schedules. Pointable sensors, selective filters, readout integration times, and on-board sample extraction functions could all be shared. Within scheduled limits, all of the latter functions could be under the direct control of the user.

Continuing with the driver requirements, the data acquisition needs are projected in Table 8. The yearly volume for these drivers is on the order of 2×10^{14} bits. Additional allowance must be made for applications not covered by the drivers as well as for the research needs. This number does provide a design goal for the data system. Doubling and tripling the data volume projected by the driver applications yields a range of 4 to 6 x 10^{14} bits per year, which will be used for the trade-off analysis on the subjects of processing, storage, and distribution.

5.3 DATA PROCESSING

Unlike the thermometer that is directly readable by a human in degrees, data remotely sensed by detectors in space requires a large amount of processing to be intelligible by either humans or application models. The principal detectors for earth observation applications sense disturbances in electromagnetic fields over the range of visible light to microwaves. The discussion of data processing will be limited to this type data. This data is frequently categorized as image data or grid point although this classification is not completely correct. The evolution of sensor systems has been such that data

Table 8. Data Requirements for Driver Applications

APPLICATION	ESTIMATED TOTAL NUMBER OF BITS REQUIRED PER YEAR X10^6	ESTIMATED INCREMENTAL BITS PER YEAR ADDITIONAL TO DATA ACQUIRED FOR PREVIOUS APPLICATIONS X10^6	CRITICAL DATA SYSTEM IMPACT	CUMULATIVE TOTAL YEARLY DATA X10^6 BITS
Agriculture	9 299 198	9 299 198	High resolution with rapid revisit with critical timing	9 299 198
Land Use	67 519 708	67 519 708	Large data volume geometric accuracy	76 818 906
Geology	25 241 777	2 404 231	Special spectral bands	79 223 137
Range Management	17 362 578	15 645 625	Large data volumes	94 868 762
Numerical Weather Forecast	21,067,079	21 067 079	Large data volumes timeliness; difficult information extraction	115 935 840
Mesosale Weather	23 996 661	23 996 666	Large data volumes relatively high resolution; timliness diff. information extraction	139 932 500
Severe Storm Warning	5 933 349	5 933 349	Frequent revisit high resolution extreme timeliness diff. infor. extrac.	145 865 840
Agricultural Meteorology	6 532 500	6 532 500	Difficult information extraction	152 398 340
Physical Oceanology	17 362 578	15 645 625	Large data volumes difficult information extraction	168 043 960
Navigation and Storm Warning	24 413 657	24 276 233	Large data volumes	192 320 190
Ice Monitoring	3 467 715	1 793 315	Difficult information extraction	194 113 500

used primarily for images was subjected to a particular type of processing and other data such as discrete atmospheric soundings was taken at particular points on a grid. Generally, the so called image data was taken by some sort of scanning instrument and the resulting data contained large amounts of spatial information. The spatial resolutions are small and the data volumes large. However, none of these characteristics are either innate or limited to 'image' data. Sounder instruments can scan, the resolutions are increasing, and images of spatial information can be constructed from the data. The distinguishing feature of the two types of data is whether or not the information is directly contained in the detected measurements or whether it must be inferred by a series of matrix inversions. For purposes of discussing data processing, the data will be referred to as type A or type B. Information is generally extracted from type A data by classification and the generation of thematic maps. Type B data must be subjected to a matrix inversion process whereby the reflectance coefficients of n channels are transformed to n coefficients representing a like number of geophysical parameters before the information can be extracted from it. The amount of time devoted to processing the measurements for any particular time and location for type B data is one to two orders of magnitude greater than for type A data. Generally, the data volumes of type B data are much less. Typically, one measurement will be taken every 100 km on a grid for type B data. All the space data must be subjected to the following four functions; format, locate, correct, and information extract. The specific processes depend upon the sensor system, the type data, and the application.

5.3.1 Format

With few exceptions, space data will be digital. There are some video cameras that transmit analog signals as well as some photo systems such as the Large Format Camera that will be used on Shuttle that will not directly provide digital data. For the bulk of the sensors, the data is digitized and encoded for transmission to the ground. The communication links handle data from different sensors and different detectors within a sensor. The data messages which are constructed onboard for digitized values from different detectors, must be rearranged accordingly to some usable format for processing. For a multispectral scanning type sensor, the relative location of each picture element or pixel must be determined. For a sensor such as the Thematic

Mapper, the band to band displacement on the ground of data taken at any instant in time is about six kilometers between band one and band six. The formatting part of the processing is necessary to determine just what data a piece of data is. For some of the active sensors that switch between excitation frequencies, the formatting function places data for like frequencies together. The significant quality about format processing is it does not alter the information content of the data and is thus not controversial from the standpoint of applications. Thus, it is a common process that can be shared by all users and should be performed as soon as possible. The ultimate is to format onboard.

Depending upon the disposition of the data, additional formatting is required. For example, data to be subjected to particular algorithms must be in compatible formats. Data to be stored may require a different format than data to be transmitted over a communication line. Some users want all the data about a particular location, while others want just one channel of data over a large area. Some scanning sensors scan back and forth while others only scan from right to left. Consistency is required for interfacing to additional processing. From a total system standpoint, the fewer transitions that the data must be subjected to, the more optimum the system design. Thus, formatting for specific algorithms should be postponed until late in the data flow.

5.3.2 Locate

Space data must be located to be usable. This includes locations in both time and space. The present approach is to regularly identify the data with time information. In addition, the position of the spacecraft, its attitude, the sensor pointing and other information about it such as any filters, voltages, and temperature are also correlated with time data. This information, called ancillary data, is essential to use the space data. At some point in the processing, this ancillary data is merged with the space data and is used to locate the data as well as to compute correction coefficients. This merging of ancillary data is a noncontroversial requirement for all users. It should be done as soon in the data flow as possible and is a good candidate for onboard processing.

5.3.3 Correct

Depending upon the point of view, some alterations to the data is either correction or corruption. Trade offs are required for this processing since not all users want the same process. The normal correction processes considered are radiometric, geometric, and atmospheric. Radiometric usually is accomplished on scanning type instruments by regularly scanning the detector passed a known source and then adjusting each signal level linearly according to the amount required to bring the known reading into specified limits. In some systems, there may be a bias introduced for each frame or group of frames, to increase the dynamic range of the sensor without sacrificing quantization or requiring more bits. Both of these types of radiometric corrections are noncontroversial and are required by nearly all users. They too should be done early. As linear arrays replace scanners in sensor systems, the methods of performing radiometric correction will change, but it it still expected to be a noncontroversial process.

Geometric correction has some controversy associated with it according to the application. The process generally involves transforming the data to some reference system. There is a physical transformation when the data is first taken according to the geometry of the sensors. Electromagnetic radiation from a curved earth travels different lengths through the atmosphere to impinge upon detectors at different locations and times. For known geometry, a reversal of the process is desired to represent the object sensed. For a nadir pointing sounder, the distortion is minimal and the measurement can be mapped onto a grid of the time and space coordinates of the satellite at the time the data was taken. For pointable imaging sensors, the process is more difficult because of the warping and complexity of the geometry. There will even be some band to band difference. For scanning sensors, the mechanical movements will impose some uncertainity. Then too, there will not be a continuous mapping function since the digital data is quantized by its nature. Thus, some resampling scheme such as nearest neighbor, bi-linear interpolation, or bi-cubic approximation (reference 23) is required. The controversies center around the method of resampling and the artificial pixel levels that may be generated. Some applications are better served by applying the raw data directly to the algorithm before geometric correction. On the other hand, geometric correction and resampling is a necessary processing step for many applications and should not be unnecessarily duplicated. The somewhat subjective recommendation is it should be provided by the data system on an optional basis and that it should not be done onboard. The necessity for geometric correction is a function of the size of the images and the displacement off radar. For small samples, on the order of a few kilometers with a few tens of kilometers from nadir, there will be very little distortion.

On the assumption that the geometric correction function will be performed on the ground as a service to the users, there are still many tradeoffs. Conclusive recommendations must await the implementation of the system and experience from users. In many cases, the current controversies can be expected to diminish as the true operational requirement and the application models are developed. The following considerations listed in Table 9 are identified for further investigation. The major impact is some transformation of data to a standard coordinate system is desirable from the standpoint of being able to correlate data from different sensors. There is also much overlap in the data near the poles so the data volume archived would double if raw data were retained. Other considerations identified in the table involved the decision of retaining data geometrically altered according to the needs of different users. This is considered further in the data storage issue.

Correction for atmospheric distortions is a somewhat esoteric process that is not universally required for each application. For type B data, it is inherent in the information extraction process. For type A data, it may take the form of non-linear correction coefficient according to calculated geometric distances from the object to the detector, correlation of data acquired from other sensors, or standard data according to empirical statistics. In any case, it should be considered as an optional service provided by the system but not generally applied to all the data.

Table 9. Geometric Correction Trade-Offs

ALTERNATIVE	MAJOR IMPACT	POSSIBLE APPROACH
Do not perform any geometric correction	o Not practical to archive data for correlation among sensors o Archived data volume will more than double because of overlap at higher latitudes o Burden will be imposed on most users	o Retain some unresampled data o Provide raw data directly to high volume users as required with no system storage o Geometrically correct data for system archival purposes
Choose different reference system	o Each system requires additional processing	o Choose one o Offer some additional system as alternative on a reimbursable basis. Evolve retention versus reprocessing on basis of experience.
Choose different resampling schemes including terrain mapping	o Each one requires additional processing	o Choose one o Offer additional methods as option on a reimbursable basis. Evaluate retention versus reprocessing on basis of experience.

5.3.4 Information Extraction

Information extraction from space data is currently left to the user or is done within the NASA data system only in the research mode. There are some functions widely needed for many applications. These should be performed within the future data system. For type A data, they include cluster classification, density slicing, edge enhancement, stretching, and change detection. For type B data, they include the matrix inversion process which involves the simultaneous solution of n equations in n unknowns for such geophysical parameters as various atmospheric constituents, soil moisture, skin temperature, salinity, wind velocity, and atmospheric pressures and temperatures. With the exception of high volume users and the needs of researchers for samples of the raw data, the matrix inversions should be applied to all the data and the geophysical parameters archived.

The synthetic aperture radar and some of the radar altimeter data also require special processing that is relatively noncontroversial but complex. The performance of this processing by the system and storing the resulting parameters reduces the amount of duplication in processing, reduces the total storage volume, and increases the number of applications that are economical.

The information extraction resulting from the exercise of user models is normally excluded from being a system function. However, for many of the users that are providing services, this is still a candidate for future trade-offs. Soil moisture and various weather applications where the results are needed as data inputs by other users fall into this category. Because of the volume and complexity of the data system, the present recommendation is to continue to exclude these functions. Some approaches at the distribution level, whereby the data system will permit users access to each other's resulting data, appear more practical at present.

5.4 DATA STORAGE

Data storage is the single most critical issue of the future data system because it is both essential and extravagant. The number 4×10^{14} bits per year of data was developed during the discussion on data acquisition. This is the data volume required for the user applications. To store this volume of data on 6250 bpi half-inch computer compatible magnetic tape would required in excess of 1.6 million reels of tape. The problem is compounded by the need to store the data at different points during the processing flow because different users want the data at different stages and because of the need to retain the data for lengthy time periods since many users require historical data. This analysis is aimed at defining a reasonable approach to data storage. Data storage requirements are segmented into buffering and archiving. Buffering is defined as storage of the intermediate data for less than one year. In many cases, it will be for milliseconds while awaiting error checks, retransmissions, etc., from the following processes. Buffering will be used to prevent loss of data or to minimize subsequent reprocessing to obtain the same data. Archiving will be for periods longer than one year and in many cases indefinite.

A generalized data flow is illustrated in Figure 3. Each node between processes is a potential storage point. In addition to providing storage for the space data, the data system must provide for collateral data that is necessary to fully utilize the space data. The users themselves may provide some collateral data, but in the interest of overall cost efficiency, much of it should be available from the system for all applications.

5.4.1 Data Storage Considerations

Before commencing with any evaluation of the desirability or undesirability of storing particular data at any specific point in the processing flow, some general considerations are in order. They are related to the time, cost, and technology of storage. Time considerations include the time needed to reformat the data for storage in a particular medium, the time to store the data, the time the data will be stored, and the time it takes to retrieve the data. This is often a function of the volume of data involved and the number of times retrieval is required. The costs involved for storage, depending upon the the media and retrieval, may include the cost of the storage device plus consumable material. A comparison of the different storage technologies for different times and costs are shown on Table 10. Different technologies lend themselves to storage at different places in the system. The faster access electronic devices are more suitable for buffers and for locations requiring data manipulation such as reformatting or extraction of portions of the data.

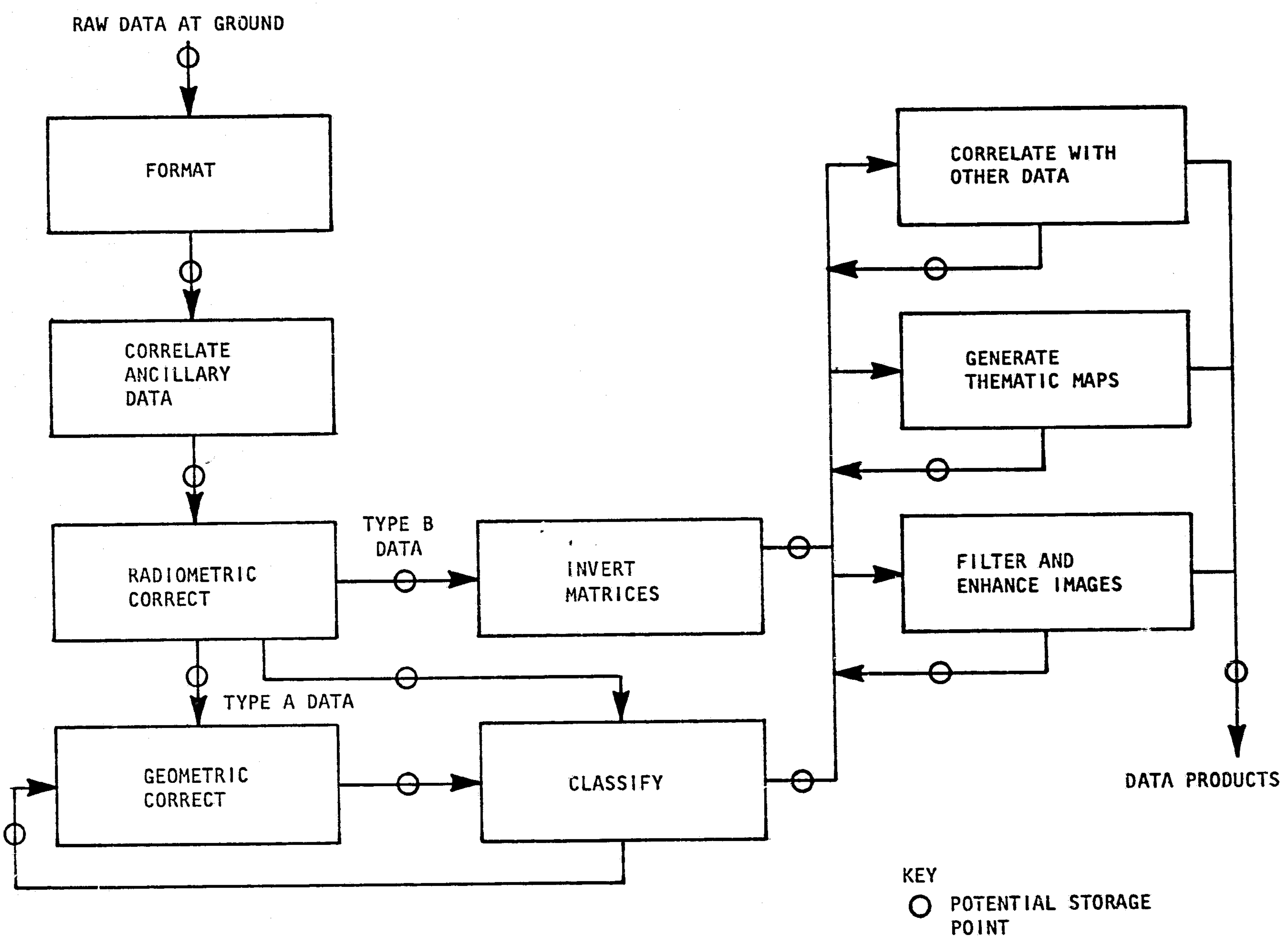

Figure 3. Potential Storage Points in Data Flow

Table 10. Comparison of Digital Storage Technologies

TECHNOLOGY	TYPICAL ACCESS TIME	USUAL STORAGE TIME	COST RANGE CENTS PER BIT	DATA VOLUMES IN MEGABITS	COMMENTS
Electronic	Nanoseconds to microseconds	Seconds	0.1 - 1.5	.5 - 5.0	Volatile; fast; on-line working storage
Magnetic Core	100s of nano-seconds	Seconds	0.1 - 0.3	.2 - 8000	Non-volatile; large power required
Charge Coupled Device (CCD)	Microseconds to milli-seconds	Minutes	0.1 - 1.0	.1 - 8	Good interface buffer to slower storage
Bubble	Milliseconds	Seconds to days	0.05 - .8	.5 - 100	Non-volatile ; high density
Rigid magnetic (discs and drums)	10s of milli-seconds	Seconds to 10s of years	.005 - 0.05	1 - 10^3	Most mature;can be portable
Flexible magnetic (tape and mass)	10s of seconds to minutes	Minutes to 2 years	10^{-7} - 10^{-3}	.25 - 10^6	Requires expensive error detection and correction
Exotic (laser, holographic, electron beam)	Microseconds	Many years	10^{-9} - 10^{-1}	10 - 10^8	Frequently read only; very suitable for archiving

Others, such as removable disks or some of the exotic approaches such as laser recording on film, are very conducive to off-line library storage. Another important consideration for some of the data system storage needs is portability of the stored data. While film is not listed in the table, it is very suitable to storing image data. It can be reproduced at a low cost and distributed inexpensively. Some of the optical disk approaches can be expected to also exhibit this advantageous quality in the future. The data in Table 10 for conventional methods was computed from some of the many storage analyses in the literature (references 24, 25, 26, 27, 28, 29, 30, 31, 32, and 33). Most of the mass storage devices employ various methods of changing magnetic tape cartridges (references 34, 35, 36, and 37). They may have some limited applications in the data system, but because of their short archival life are not suitable to the archival needs for space data. The exotic storage devices such as the electron beam (BEAMOS) (reference 38), or the optical systems (references 39 and 40) offer both the densities and the long term storage stability required for archiving the large volumes of space data. While they are still in an early stage of development, the needs of such devices have been sufficiently established that they can be expected to be readily available in reliable commercial versions by the mid 1980's.

5.4.2 Data Storage Locations

The questions of "What data should be stored?," "Where should it be stored?," and "How should it be stored?" are best considered according to the data flow of Figure 3. Each of the nodes following a functional process is a potential storage point. A certain amount of temporary storage is required as buffers to accommodate differences in quantities, complexion, and processing rates for different functions throughout the system. The load leveling benefit will enable more economical sizing of the data handling facilities. It will also provide some relief from availability requirements. The important consideration for the use of buffer storage is that it not be so large as to permit backlogs of data that will impact the timeliness of the delivered data products. A sizing goal is a system capable of processing all the acquired data on the average using 90 percent of the system capacity and to be able to commence processing 80 percent of the jobs within one hour of receipt of the data. Then, buffers can be sized to accommodate the one-hour delay and the appropriate delays for the remaining 20 percent of the jobs. In many cases, the receipt of large jobs will be sufficiently separated that extensive buffers will not be required. Storage for overflow conditions can be accommodated with magnetic tape. High density digital tape will currently hold 10^{11} bits per reel. Other media is more appropriate for different conditions.

A point by point analysis of each potential storage node of Figure 3 is presented in Table 11. Recommendations or other factors are presented in the column labeled comments. There may be some who will argue that the rationale for not retaining data at each node was arbitrary but the total impact of such an approach is illustrated by the following example. For this example, only one sensor, a Thematic Mapper on a Landsat D satellite with a 16 day revisit orbit, will be used. The data storage requirement for 100 percent retention at each of the first six nodes of Figure 3 is determined.

Example 1 - 100 percent data storage for 1 sensor for 1 year

Given: 1 Thematic Mapper

16 day revisit time

4 visible bands at 30 meter spatial resolution

2 near IR bands at 40 meter spatial resolution

1 far IR band at 120 meter spatial resolution

8 bit quantization level

Data acquired over land only = .27

Visible and near IR bands acquire data only in daylight = .5

Equatorial circumference of the earth = 40075 Km

Polar circumference of the earth = 39941 Km

Swath width = 185 Km

World land area = 148940540 Km^2

Assumptions: Orbital ground trace equals polar circumference of earth

Minimum equatorial overlap

No cloud editing

No excess pixels required due to band to band displacement

The number of orbits can be determined by equation 1-1.

$$\text{Number of Orbits} = \frac{\text{Integer of equatorial circumference}}{\text{swath width}} \qquad (1\text{-}1)$$

$$= \frac{40075}{185} = 216.6$$

217 orbits in 16 days = 13.5625 orbits per day.

The calculation of the number of pixels per orbit is the product of the number of cross track pixels times the number of along track pixels. The cross track pixels are determined according to equation 1-2 and the along track pixels according to equation 1-3.

$$\begin{matrix}\text{Number of Cross}\\ \text{Track Pixels}\end{matrix} = \frac{\text{swath width}}{\text{spatial resolution}} = \frac{185 \times 10^3 \text{ meter}}{\text{SR}} \qquad (1\text{-}2)$$

SR = 20, 40, or 120

$$\begin{matrix}\text{Number of Along}\\ \text{Track Pixels}\end{matrix} = \frac{\text{orbital ground trace}}{\text{spatial resolution}} = \frac{39941 \times 10^3}{\text{SR}} \qquad (1\text{-}3)$$

The data volume is determined according to equation 1-4.

$$\begin{matrix}\text{Yearly Data}\\ \text{Volume}\end{matrix} = \begin{pmatrix}\text{pixels}\\ \text{per}\\ \text{orbit}\end{pmatrix} \text{X} \begin{pmatrix}\text{orbits}\\ \text{per}\\ \text{day}\end{pmatrix} \text{X} \begin{pmatrix}\text{number}\\ \text{of}\\ \text{bands}\end{pmatrix} \text{X} \begin{pmatrix}\text{percent}\\ \text{land}\end{pmatrix} \text{X} \qquad (1\text{-}4)$$

$$\begin{pmatrix}\text{day/}\\ \text{night}\\ \text{factor}\end{pmatrix} \text{X} \begin{pmatrix}\text{bits}\\ \text{per}\\ \text{pixel}\end{pmatrix} \text{X} \begin{pmatrix}\text{days}\\ \text{per}\\ \text{year}\end{pmatrix}$$

$$= \begin{matrix}\text{percent}\\ \text{per}\\ \text{orbit}\end{matrix} \text{ X } 13.5625 \times (N) \text{ X } .27 \text{ X } \begin{pmatrix}0.5\\ 1.0\end{pmatrix} \text{ X}$$

$$8 \text{ X } 365$$

$$= 10692.675 \text{ X volume}$$

Volumes are listed below for each resolution band.

Resolution	Cross Track	Track	Bands	Day/ Night	Volume
30	6167	1.331367×10^6	4	.5	16421.08×10^6
40	4625	$.998525 \times 10^6$	2	.5	4618.1781×10^6
120	1542	$.332842 \times 10^6$	1	1.0	513.24236×10^6
TOTAL					21552.5×10^6

The yearly volume is $230,453,870 \times 10^6$ bits.

This volume of data of 2.3×10^{14} bits per year is the total volume of data per year that could be acquired by the Thematic Mapper in a 16-day revisit orbit if it were not constrained by power budgets, operating consideration, communication links, or ground processing restrictions. This is the data volume that would require storage upon receipt at the ground if no one would impose any restrictions on data taking or storage.

If the decision were made to record all the data at each of the nodes shown in Figure 3, this same volume of data would be stored at each of nodes two, three, and four. For this example, the data would be subjected to geometric correction after radiometric correction. At that point, the overlap would be removed so a new data volume will result.

For a land area of 148940540 Km^2, the data volume as shown below will result.

Resolution	Bands	Bits per Coverage	Repeat in Days	Number of Repeat/ Year	Total Year Bits $\times 10^6$
30	4	5295663.3×10^6	16	22.8125	120807310
40	2	1489405.3×10^6	16	22.8125	33977058
120	1	82744.7×10^6	8	45.625	3775227
TOTAL					158559580×10^6

On the assumption that only one classification map will be generated from the 8 channels of data every 16 days or 23 times per year, an additional 30450063×10^6 bits of data will require storage at node 6.*

The total storage requirements are presented as follows:

Node	Following	Bits Per Year
1	Receiving	$230\ 453\ 870 \times 10^6$
2	Formatting	$230\ 453\ 870 \times 10^6$
3	Correlation	$230\ 453\ 870 \times 10^6$
4	Radiometric Correction	$230\ 453\ 870 \times 10^6$
5	Geometric Correction	$158\ 559\ 580 \times 10^6$
6	Classification	$30\ 450\ 063 \times 10^6$
	TOTAL	$1384\ 875\ 600 \times 10^6$

The continuation of a de facto archiving practice of all the data passed through each node would result in a whopping 1.4×10^{15} bits per year for just one sensor. Obviously, data must be discarded and the temptation to save buffered data past its intended life because it may be useful in the future must be rejected. It may be that agreement in principal against saving all the raw data at each processing node already exists, but there is still little agreement among both users and processors on what data should be discarded. The data volumes for acquisition indicated in Table 7 result from an engineering assessment unpredjudiced by any favorite applications. These volumes can reflect the corresponding storage requirements throughout the system according to the analysis of Table 11. As the data system matures, adjustments for specific data products can be expected but the resulting total volume is not expected to deviate markedly from the values presented in this report. An additional data storage consideration is the need for storing collateral data.

*The thermal IR with an 8-day repeat will provide 2 channels for use in classification.

Table 11. Storage Analysis

STORAGE LOCATION (Portrayed on Figure 3)	ADVANTAGES	DISADVANTAGES	COMMENTS
1. Immediately upon receipt at ground	o A copy of all data will be available to reconstruct all future needs in case of loss o The need for real-time subsequent processing will be reduced. o Data will not be lost due to downstream equipment failure.	o Data volume in excessive. o All data must be processed before it will be useable for any user. o If downstream equipment is not sized for real-time processing, the backlog will become unstable.	o Provide short-term buffer capability to prevent data loss due to downstream equipment failure. Optimum time sizing requires further study. One to twenty-four hours is range required. o Use non-transportable media. Use rigid magnetic, bubble, CCD, or electronic according to time trade-off results.
2. After formatting and before correlation with ancillary data	o Data utility will not be compromised because of delay in receiving ancillary data. o The need for real-time correlation will be reduced.	o Only a small percentage of users could use the data in the uncorrelated condition. o Storage at each node in system results in an overall excess storage that will hamper data management.	o Most ancillary data will be packetized on-board, possibly within the same data packet; however, some could get separated due to delay in communication packet forming. o Provide minimum amount of short term buffer capability (about 1 hour) to allow for asynchronous receipt of necessary information. o Provide additional backup such as magnetic tape for contingency situations.

Table 11. Storage Analysis (Continued)

STORAGE LOCATION (Portrayed on Figure 3)	ADVANTAGES	DISADVANTAGES	COMMENTS
3. After correlation with ancillary data and before the application of radiometric correction	o Some users require unaltered data.	o Radiometric correction is usually easy enough to be done in real-time. o Desirable to minimize stored data whenever possible.	o Only a small percentage of users can use non-radiometric corrected data. o A sampling of the "raw" data should be preserved for about 1 month. Magnetic tape would be applicable. o A small sample should be archived for reference and future calibration.
4. After radiometric correction and before geometric correction, classification, or matrix inversion	o Many users require the data before it is subjected to these processes. o The subsequent processes are lengthy and it would be extravagant to size the system to perform them in real-time.	o Satellites acquire data according to non-uniform ground traces. Data in this sequence is not suitable to data basing, retrieval, or correlation with other data. o Data in this sequence includes excessive observation at the polar latitudes, thus burdening any data base with an imbalance of excess data. Geometric correction and redundancy removal will reduce data volume about 50 percent.	o A limited sample of the unresampled data should be archived. Samples should include global coverage on a seasonal basis. Frequent revisits for selected limited region, and other as required by bonefide users. o Unresampled data required for high volume users should be buffered to the minimum capacity consistent with their ability to accept the data (1 day maximum).

Table 11. Storage Analysis (Continued)

STORAGE LOCATION (Portrayed on Figure 3)	ADVANTAGES	DISADVANTAGES	COMMENTS
5. After geometric correction and before classification	o This data is in the form useable by the greatest number of users. o Data is correlated to some standard grid that is amenable to retrieval. o Data on the environment is a transient commodity that if not retained, can never again be obtained. Once obtained it should be retained because future technology can use it in unforseen ways.	o Most require classified data. The volume of data are so great that it would be better to archive classification maps rather than unclassified data.	o This should be the bulk of the archived data. o Other archived forms should be supplementary.
6. After classification	o Classification is an extensive processing requirement. Most users need classified data. Storage of the classified data will reduce overall processing requirements.	o Each user has his own classification algorithm and requirements.	o Some unsupervised classification maps should be archived. This should be a sampling of total data. o Some temporary buffering (1 month) of current data, classified on user request basis, should be saved pending experience of user requests for current data.

Table 11. Storage Analysis (Continued)

STORAGE LOCATION (Portrayed on Figure 3)	ADVANTAGES	DISADVANTAGES	COMMENTS
7. After matrix inversion	o Users require geophysical parameters. They only use the raw data because the geophysical units are not available. o Data about the environment is a transient commodity that if not retained can never again be obtained.	o The users requiring historical data on geophysical units should maintain their own data bases in the formats they require.	o Geophysical units data of global interest should be archived. It is a small volume relative to the raw data before matrix inversion.
8. After correlation with other data	o The correlation and accompanying resampling processes are large processing jobs. Retention of the data products will reduce the amount of processing required.	o The combinations correlation will result in far too much data to be saved. o Most users will need correlated products that are not saved anyway. It is inconceivable that all the data should be correlated as a routine operation.	o Data should be correlated according to specific user requests. The resulting data products should be retained a reasonable period of time to be established by operational usage. A 30-day initial period is suggested.

Table 11. Storage Analysis (Continued)

STORAGE LOCATION (Portrayed on Figure 3)	ADVANTAGES	DISADVANTAGES	COMMENTS
9. After thematic maps are generated	o The generation of thematic maps is a lengthy process and once generated, they should be kept.	o It is impractical to generate thematic maps as a routine operation on the data. They should be generated only in response to user requests. There will be so many possibilities that the chance for reuse will be minimum.	o The digital data should not be retained unless subsequent operational experience indicates an operational savings. o They should be retained on film in reproducible form.
10. After filtering and enhancement of images	o Many enhancement and filtering operations are beneficial to many users and retention would reduce the total system processing requirement.	o The results of these utility functions are subjectively beneficial according to the requirements of individual users. o Retention will result in excessive data storage that will reduce the response performance of the data management system.	o Filtering and enhancement operations should be available as utilities to users, but the resulting data products should not be retained by the system. o Some storage functions for user products may be provided by the system in response to user needs. The responsibility for the data should fall on the user.

5.4.3 Collateral Data Storage

Nearly every application of space data requires collateral data to aid in the development or the interpretation of the resulting information. Many applications can effectively use the same collateral data. Some collateral data can be employed within the system processing to reduce the difficulty of reducing the data. Several types of collateral data can be maintained by the data system for a more cost effective end to end application than if the users had to maintain all of their own data bases.

Some of the principal candidates for collateral data as part of the NASA data system data base are those things that change slowly, those that are widely used by many applications and those that are obtained during instrument development programs such as shuttle flights. Synthetic aperture radar data, Large Format Camera film images and the resulting digitized data, and reflection and absorption properties of various atmospheric constituents are such data. Demographic information and data obtained via aircraft also are candidates for inclusion. Various types of surface truth data are also desirable as well as soil maps, cultural practices and ground control points. However, there is the problem of maintaining currency. While these items are desirable from an overall cost effectiveness standpoint, they do require an active acquisition and management system.

The collateral data requirements for each of the surrogate applications are listed in Table 12. Some of the collateral data is not applicable to certain applications and is so identified by "N/A." The degree to which the collateral data should be maintained by the data system is indicated by a "yes" when it is a good candidate, a "probable" when it has a wide range of applications although probably not now a legitimate NASA data system activity, a "doubtful" when the applications are limited or require specialized acquisition and maintenance, and a "no" if the utility of the applications would not be enhanced by being generally available via the data system.

5.5 DATA DISTRIBUTION

The applications of space data envisioned in the earth resources management and environmental monitoring areas have been shown to involve a diverse community of users with needs ranging from a specific geophysical value such

Table 12. Application Collateral Data Requirements

COLLATERAL DATA REQUIREMENT	APPLICATION - IS DATA A CANDIDATE FOR SYSTEM DATA BASE								
	AGRICULTURE	LAND USE RANGELAND	LAND USE FORRESTRY	LAND USE HYDROLOGY	LAND USE CARTOGRAPHY	LAND USE GEOLOGY	WEATHER	PHYSICAL OCEANOGRAPHY	SEA ICE & NAVIGATION
SHUTTLE SAR IMAGES	YES	YES	YES	YES	YES	YES	N/A	YES	YES
SHUTTLE LRC PHOTOS	YES	YES	YES	YES	YES	YES	N/A	YES	YES
DIGITIZED LFC IMAGES	YES	YES	YES	YES	YES	YES	N/A	YES	YES
AGRICULTURAL STATISTICS	DOUBT	N/A	N/A	DOUBT	N/A	N/A	N/A	N/A	N/A
REAL TIME METEOROLOGICAL	PROB	PROB	PROB	PROB	N/A	N/A	PROB	PROB	PROB
WEATHER & CLIMATE STATISTIC	PROB	PROB	PROB	N/A	N/A	N/A	DOUBT	N/A	PROB
SURFACE TRUTH	PROB	YES	YES	YES	YES	YES	N/A	PROB	PROB
COUNTY MAPS	NO	NO	NO	NO	NO	NO	N/A	N/A	N/A
DIGITIZED COUNTY MAPS	DOUBT	DOUBT	DOUBT	DOUBT	DOUBT	DOUBT	N/A	N/A	N/A
PLANT SPECIES INFORMATION	NO	NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CROP CALENDARS	NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PLANTING PRACTICE	DOUBT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SOIL MAPS	YES	N/A	N/A	PROB	N/A	PROB	N/A	N/A	N/A
DISASTER ALERT	DOUBT	DOUBT	DOUBT	NO	N/A	NO	NO	DOUBT	DOUBT
LIVESTOCK CENSUS	N/A	NO	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MANAGEMENT PRACTICES	N/A	DOUBT	DOUBT	N/A	N/A	N/A	N/A	N/A	N/A
WATER MANAGEMENT ACTIONS	NO	NO	NO	NO	NO	NO	N/A	N/A	N/A
GEOLOGICAL	N/A	DOUBT	DOUBT	DOUBT	DOUBT	DOUBT	N/A	N/A	DOUBT
HEAT CAPACITY MAPS	N/A	N/A	N/A	N/A	YES	YES	N/A	N/A	PROB
OWNERSHIP	N/A	NO	DOUBT	NO	DOUBT	DOUBT	N/A	N/A	N/A
DEMOGRAPHIC MAPS	N/A	N/A	N/A	PROB	PROB	N/A	N/A	N/A	N/A
DATA BOUY DATA	N/A	N/A	N/A	PROB	N/A	NO	DOUBT	YES	PROB
GEOID	N/A	N/A	N/A	N/A	PROB	PROB	N/A	YES	PROB
ICEBERG LOCATIONS	N/A	N/A	N/A	N/A	N/A	N/A	DOUBT	DOUBT	DOUBT
ATMOSPHERIC PROPERTIES	N/A	N/A	N/A	N/A	N/A	N/A	YES	YES	YES

as temperature requested from ten different geographic locations once a month, to the need for thousands of megabits per day in the form of unprocessed image data delivered continuously to a central processing facility. The satisfaction of such requirements dictates the need for an extremely flexible distribution system. The system must have streamlined processing and delivery capability with a minimum of human intervention. It also implies a hierarchy of processing functions. The unsophisticated user can only be satisfied if his specialized processing needs are performed only on the data he needs as it is requested. The large volume user can be satisifed by not performing any excess processing on the data he requires.

Closely correlated with the ability to distribute data products in a timely manner is the need to minimize the excess data flowing in the system. Just as specialized processing can be minimized by doing it on an "as requested" basis only, so can specialized data acquisition be accommodated on an "as requested" basis. To implement this approach to data acquisition, two functions must be provided. One is an interactive user acquisition function and the other is a total data acquisition capability mission model. Not all requests for specialized data can be accommodated immediately. Some may require the favorable positioning of a sensor and others may require the availability of the resource which may be committed to supplying other data needs. An additional function of cost accounting and priority resolution is needed if the system is to respond to specialized needs. In the past, the users paid for the cost of duplicating and delivering data products. If a limited amount of resources are to be allocated for specialized data acquisition, the cost of the data itself will require a chargeback according to use. A multi-level tariff structure seems appropriate since some users can wait to obtain their data on a non-impact basis with other users with emergency needs.

Certain data processing functions, such as classification, image enhancement, and measurement correlation among data from several sensors can best be performed for the small user as a system utility. Again, the charges for these services can be levied according to established tariffs much as computer time shared systems currently operate. The only difference is the data system would be supplying the data and the algorithms.

The synergism of the many applications poses an additional data distribution problem. For example, many agricultural applications require meteorological and soil moisture data derived from space radiometry. This same data may be used for weather applications to generate atmosphere coefficients and data inputs to weather models. The outputs of the weather models may also be the meteorological and soil moisture needed for agricultural application. The results of the agricultural soil moisture models may also be input to the weather models. This is not an unworkable problem for large users such as the National Weather Service or the U.S. Department of Agriculture and in spite of the bureaucratic obstacles, the exchange of data between such users can be expected to be effected. However, if the users are private concerns, or smaller agencies without established policies for data exchange, the overall system efficiency will be hampered. A beneficial data system function would be to provide for the interchange of data from users' private data bases. There would be many problems such as cost accounting, data integrity, access control, and liability that would need study and resolution. Additional technical problems such as format compatibility and data base management would need solving. This function of providing access to users' private data bases is not expected to come about until the later stages of data system implementation.

The cost of delivery of the space data products is a major factor in user acceptance of the system. The choice of transportation media should be carefully matched with timeliness requirements. The need for interactive requests and the response times available through digital electronic data transfer presupposed a digital data network. However, for many users, this can be via the commerical communications channels such as the proposed 56 kilobit Advanced Communication Service (ACS) (references 41 and 42) or Xerox Telecommunication Network (XTEN) (reference 43). For the very low volume user, the standard voice grade telephone circuits and modems will be adequate. A trade-off is required for each application requiring large data volumes. If timeliness is a legitimate requirement and the application can justify the cost of dedicated communication links, wide band channels such as fiber optics or satellite to ground station links are in order. The cost advantage of physical transport should not be neglected if some delay in delivery can be tolerated. The current method of shipping computer compatible magnetic tapes has drawbacks of being expensive and requiring substantial data processing delays in production of the tape. Film transparencies have the drawback of requiring digitizing for many applications. Future methods such as holographic or laser recording on specially prepared substrates are likely to be the favored approach for delivery of large data volumes for most applications. The economics of these approaches are closely related to the selection of data storage methods. The cost of the delivered product is a function of both the cost of production and the cost of transportation.

5.6 KEY ISSUE SUMMARY

While the issues of timeliness, data acquisition, data processing, data storage, and data distribution were analyzed separately, the resolution of each is dependent upon the approaches used to resolve the other problems. Limiting data acquisition, alleviates some of the delays in processing, thus improving timeliness of the delivered product. There are trade-offs between timeliness and data distribution costs. There are trade-offs between data storage and reprocessing. The complexity of the data system requirements to apply space data to users' needs is such that no single analysis will suffice to design and implement the optimum system. A series of iterations will be required with analyses of the salient problems in a general way, followed by a limited implementation of benefit to some users with a continual upgrade in system capacity, functions, and applications served. The resulting single most important requirement for the data system is flexibility to accommodate changing requirements as the system is implemented.

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APPENDIX A

This appendix contains a listing of the application of space data that were considered in the selection of the dri[illegible] application of the study. Table B in this appendix contains the detailed data acquisition requirements for the driver applications. The data volumes for each observation requirements were calculated according to equation A-1.

$$V = \sum \frac{A}{(SR)^2} \times Q \times B \times F \times N \qquad \text{(A-1)}$$

where

- V is the total bits per year observation requirement
- A is the areal extent
- SR is the spatial resolution of each band
- Q is the quantization level in bits
- B is the number of bands at a particular spatial resolution
- F is the factor for sample size
- N is the number of observations required per year

APPENDIX

TABLE A

APPLICATIONS OF SPACE DATA

I. EARTH RESOURCES MANAGEMENT

A. AGRICULTURE

1. CROP CULTIVATION INVENTORY
2. CROP PLANTING PROGRESS
3. CROP TYPE AND AREA DETERMINATION
4. CULTURAL PRACTICES EVALUATION
5. CROP PHENOLOGY MONITORING
6. PLANTING DATE ADVISORY
7. CROP INVENTORY
8. CROP YIELD AND PRODUCTION FORECASTING
9. IRRIGATED CROP INVENTORY
10. NOXIOUS WEEDS ASSESSMENT
11. INSECT AND DISEASE MONITORING
12. CROP MOISTURE STRESS ASSESSMENT
13. NUTRIENT DEFICIENCY OR EXCESS SALINITY ASSESSMENT
14. DISASTER DAMAGE ASSESSMENT
15. DETERMINE SOIL TEMPERATURE TO WATER DEPLETION RELATIONSHIPS
16. FREEZE DAMAGE ASSESSMENT
17. EARLY WARNING OF PRODUCTION SHORTFALLS
18. PROGRAM AND POLICY EFFECTIVENESS ASSESSMENT
19. DATA FOR POLICY DECISION
20. DATA FOR LEGISLATIVE ACTIONS
21. ASSESS COMPLIANCE AND EFFECTIVENESS OF VOLUNTARY PROGRAMS
22. MAP MATURITY HOMOLOGS
23. PLAN LOGISTICS OF FEED AND FERTILIZER
24. PLAN LOGISTICS OF HARVEST SUPPORT
25. PREDICT WORLD DEMANDS FOR FOOD AND FIBER

26. MONITOR IMPACT OF WEATHER ON HARVEST PROGRESS
27. IDENTIFY ISLANDS OF DISEASE RESISTANCE
28. MONITOR COMPLIANCE WITH LOAN SECURITY PROGRAMS
29. MONITOR COMPLIANCE WITH PLANTING LIMITATIONS

B. LAND USE

1. SURFACE WATER BODY MAPPING
2. PLAYAS LAKE MAPPING
3. RIVER RUNOFF MAPPING
4. WETLAND INVENTORY
5. VEGETATION SPECIES MAPPING
6. LAND COVER MAPPING
7. FOREST INVENTORY
8. FOREST PRODUCTIVITY ASSESSMENT
9. FOREST CLEARCUT ASSESSMENT
10. WILDLIFE HABITAT EVALUATION
11. CARTOGRAPHY
12. GEOLOGICAL MAPPING
13. LINEAMENT MAPPING
14. ROCK TYPE MAPPING
15. LANDFORM MAPPING
16. THERMAL INERTIA MAPPING
17. DETERMINATION OF SOIL MOISTURE TO GEOLOGICAL STRUCTURE RELATIONSHIP
18. MINERAL SURVEYS AND INVENTORIES
19. POWER PLANT SITING
20. COMPREHENSIVE PLANNING
21. HIGHWAY PLANNING
22. GEOTHERMAL POTENTIAL ANALYSIS
23. WATER CIRCULATION
24. LAKE EUTROPHICATION SURVEY
25. IRRIGATION DEMAND ESTIMATE
26. WATER RESOURCES PLANNING AND MANAGEMENT
27. HYDROCARBON EXPLORATION
28. GEOBOTANICAL STUDIES
29. URANIUM EXPLORATION
30. LANDSLIDE MAPPING

31. LANDFORM CHANGES
32. ERROSION CONTROL MONITORING
33. ILLEGAL SURFACE MINING DETECTION
34. SOLID WASTE MANAGEMENT
35. FLOOD PLAIN DELINEATION
36. FIRE FUEL POTENTIAL
37. FLOOD CONTROL MAPPING AND DAMAGE ASSESSMENT
38. FLOOD RECOVERY OPERATIONS
39. RANGELAND MANAGEMENT
40. SOIL CLASSIFICATION AND MAPPING
41. SOIL MODEL DEVELOPMENT
42. SOIL EROSION
43. CONSERVATION PRACTICES ASSESSMENT
44. RANGELAND ACCESS CONTROL
45. RANGELAND FORAGE TYPE AND YIELD INVENTORY
46. RANGELAND REHABILITATION
47. DESIGN OF RANGELAND LEGISLATION
48. GOVERNMENT RANGELAND PROGRAM COMPLIANCE MONITORING
49. EPISODE DAMAGE TO RANGELAND ASSESSMENT
50. DREDGE AND FILL PERMIT ISSUANCE
51. OIL AND GAS LEASE SALES
52. MARSH SALINIZATION
53. CHEMICAL AND INDUSTRIAL WASTE POLLUTION

II. ENVIRONMENTAL MONITORING

A. WEATHER AND CLIMATE

1. WEATHER MODEL GEOPHYSICAL UNIT MEASUREMENT
2. SYNOPTIC CLOUD COVER
3. SYNOPTIC SKIN TEMPERATURE
4. SYNOPTIC MOISTURE
5. ATMOSPHERE CONSTITUENTS
6. RADIATION SPECTRUM
7. SURFACE PRESSURE
8. ATMOSPHERIC WATER VAPOR
9. CLOUD HEIGHT

10. WIND VELOCITY
11. AIR CURRENTS
12. PRECIPITATION MEASUREMENTS
13. PRECIPITATION MAPPING
14. SKY COVER
15. VISIBILITY
16. DEWPOINT DETERMINATION
17. STORM DETECTION
18. STORM TRACKING
19. STORM SEVERITY ASSESSMENT
20. TEMPERATURE PROFILE
21. HUMIDITY PROFILE
22. PRESSURE PROFILE
23. URBAN HEATING PATTERNS
24. AGRICULTURAL WEATHER
25. SOIL FROST
26. LAND SURFACE TEMPERATURE
27. CLIMATE STATISTICS
28. DESERTIFICATION
29. GLOBAL BIOMASS MONITORING
30. UPPER ATMOSPHERE RADIATION MONITORING
31. SOLAR FLUX
32. SURFACE ALBEDO

B. OCEAN MONITORING

1. PHYSICAL OCEANOGRAPHY
2. OCEAN TOPOGRAPHY MAPPING
3. SEA STATE MONITORING
4. SEA STATE PREDICTION
5. SEA SURFACE AIR INTERACTION MODEL DEVELOPMENT
6. OBTAIN SEA DATA INFLUENCING WEATHER CONDITIONS
7. WAVE HEIGHT
8. WAVE DYNAMICS SPECTRUM
9. TIDAL WAVE PHASE AND AMPLITUDE DETERMINATION

10. WIND DIRECTION MAPPING
11. SILENT AREA LOCATION
12. CURRENT MAPPING
13. CURRENT CHANGE DETECTION
14. COASTAL HYDROLOGY OF ESTUARIES
15. SALINITY MAPPING
16. CHLOROPHYLL DETECTION
17. CHLOROPHYLL INVENTORY
18. SUSPENDED PARTICLE DETECTION
19. OIL SPILL DETECTION
20. OIL SPILL IDENTIFICATION
21. POLLUTION SOURCE LOCATION
22. POLLUTION EFFECTS PREDICTION
23. THERMAL MAPPING
24. MINERAL LOCATION
25. UNDERSEA OIL SEAPAGE DETECTION
26. POLLUTION DISPERSEMENT
27. FAUNA MIGRATION PATTERNS
28. BIOLOGICAL OCEANOGRAPHY
29. FISH FEEDING AREA LOCATION
30. UPWELLING LOCATION
31. POLAR ICE INVENTORY
32. ICE SALINITY
33. ICE AGE AND THICKNESS
34. ICE BOUNDARY MIGRATION
35. ICE FLOW PATTERNS
36. ICEBERG TRACKING
37. NAVIGATION HAZARDS
38. NAVIGATION ROUTE SELECTION
39. NAVIGATION THROUGH PACK ICE
40. SHIPPING SEASON EXTENSION
41. ICE FORMATION FORECAST
42. ICE MELT FORECAST
43. OFFSHORE STRUCTURE HAZARDS WARNING
44. SEARCH AND RESCUE AID

APPENDIX -- TABLE B. DATA VOLUMES

OBSERVATION REQUIREMENT	TYPE MEASUREMENT	SPATIAL RESOLUTION IN METERS	QUANTIZATION LEVEL PER BAND	SAMPLE SIZE	AREAL EXTENT AND AREA IN $(KM)^2$	TOTAL BITS PER OBSERVATION	NUMBER OF OBSERVATIONS	TOTAL BITS PER YEAR $X 10^6$	TOTAL BITS PER YEAR PER OBSERVATION REQUIREMENT
1	4 BANDS VISIBLE	30	8	100%	TOTAL LAND	$5295663.3 X 10^6$	1	5295663.3	
	2 BANDS NEAR IR	40	8		AREA 148 940 540	$1489405.3 X 10^6$	1	1489405.3	$6785068.5 X 10^6$
2	4 BANDS VISIBLE	30	8	1%	EST. WORLD	$26666.7 X 10^6$	8	213333.3	
	2 BANDS NEAR IR	[illegible]	8		AGRICULTURAL	$7500.0 X 10^6$	8	60000.0	
	1 BAND THERMAL IR	[illegible]	8		LAND 75 000 000	$416.7 X 10^6$	8	3333.3	
	4 BAND VISIBLE	15	8	.1%		$10666.7 X 10^6$	8	85333.3	
	5 BAND PASSIVE MW	30KM	10	100%		$125.0 X 10^6$	1	125.0	
	2 BAND ACTIVE MW	1KM	10	100%		$1500.0 X 10^6$	1	1500.0	
	3 BAND STEREO IMAGE	15	8	1%		$80000 X 10^6$	1	80000.0	
	RADAR IMAGE	25	10000	.01%		$120000 X 10^6$	1	120000.0	$563624.9 X 10^6$
3	4 BANDS VISIBLE	30	8	.5%	EST. WORLD	$13333.3 X 10^6$	20	266666.7	
	2 BANDS NEAR IR	40	8		AGRICULTURAL	$3750.0 X 10^6$	20	75000.0	
	1 BAND THERMAL IR	120	8		LAND 75 000 000	$208.3 X 10^6$	20	4166.7	
	4 BAND VISIBLE	15	8	.05%		$5333.3 X 10^6$	20	106666.7	
	3 BAND STEREO IMAGE	15	8	.2%		$16000.0 X 10^6$	1	16000.0	
	RADAR IMAGE	25	10000	.01%		$120000.0 X 10^6$	1	120000.0	$588500.1 X 10^6$
4	4 BAND VISIBLE	30	8	.5%	EST. WORLD	$13333.3 X 10^6$	20	266666.7	
	2 BAND NEAR IR	40	8		AGRICULTURAL	$3750.0 X 10^6$	20	75000.0	
	1 BAND THERMAL IR	120	8		LAND 75 000 000	$208.3 X 10^6$	20	4166.7	
	4 BAND VISIBLE	15	8	.05%		$5333.3 X 10^6$	20	106666.7	
	3 BAND STEREO IMAGE	15	8	.2%		$16000.0 X 10^6$	1	16000.0	$588500.1 X 10^6$
5	4 BAND VISIBLE	30	8	.5%	EST. WORLD	$13333.3 X 10^6$	5	66666.5	
	2 BAND NEAR IR	40	8		AGRICULTURAL	$3750.0 X 10^6$	5	18750.0	
	1 BAND THERMAL IR	120	8		LAND 75 000 000	$208.3 X 10^6$	5	1041.5	
	4 BAND VISIBLE	15	8	.01%		$1066.7 X 10^6$	5	5333.3	
	3 BAND STEREO IMAGE	15	8	.01%		$800.0 X 10^6$	1	800.0	$92591.3 X 10^6$

OBSERVATION REQUIREMENT	TYPE MEASUREMENT	SPATIAL RESOLUTION IN METERS	QUANTIZATION LEVEL PER BAND	SAMPLE SIZE	AREAL EXTENT AND AREA IN $(KM)^2$	TOTAL BITS PER OBSERVATION	NUMBER OF OBSERVATIONS	TOTAL BITS PER YEAR $\times 10^6$	TOTAL BITS PER YEAR PER OBSERVATION REQUIREMENT
6	5 BAND NEAR IR	1KM	10	100%	EST. WORLD	3750.0×10^6	13	48750.0	
	5 BAND PASSIVE MW	30KM	8	100%	AGRICULTURAL	100.0×10^6	13	1300.0	
	2 BAND ACTIVE MW	30KM	8	20%	LAND 75 000 000	8.0×10^6	13	104.0	
	2 BAND ACTIVE MW	1KM	8	1%		12.0×10^6	13	156.0	50310.0×10^6
7	4 BAND VISIBLE	30	8	1%	WINTER WHEAT	3625.8×10^6	4	14503.2	
	2 BAND NEAR IR	40	8	1%	AREA = 50% OF	2039.5×10^6	4	8158.0	
	1 BAND THERMAL IR	120	8	20%	TOTAL WORLD WHEAT	1133.1×10^6	4	4532.3	
	5 BAND IR	1KM	10	100%	AREA 10 197 700	10.2×10^6	30	305.9	27499.4×10^6
8	4 BAND VISIBLE	30	8	10%	EST. WORLD	266666.7×10^6	1	266666.7	
	2 BAND NEAR IR	40	8	10%	AGRICULTURAL	75000.0×10^6	1	75000.0	
	1 BAND THERMAL IR	120	8	10%	LAND 75 000 000	520.8×10^6	1	520.8	
	4 BAND VISIBLE	15	8	.01%		1066.7×10^6	4	4266.7	
	5 BAND PASSIVE MW	30KM	10	10%		12.5×10^6	4	50.0	
	2 BAND ACTIVE MW	1KM	10	10%		150.0×10^6	4	600.0	
	3 BAND STEREO IMAGE	15	8	.1%		8000.0×10^6	2	16000.0	
	RADAR IMAGE	25	10000	.01%		120000.0×10^6	2	240000.0	603104.2×10^6
9	4 BAND VISIBLE	30	8	100%	TOTAL LAND	5295663.3×10^6	4	21182653	
	2 BAND NEAR IR	40	8	100%	AREA 148 940 540	1489405.3×10^6	4	5957621	
	1 BAND THERMAL IR	120	8	100%		82744.7×10^6	8	661958	
	3 BAND STEREO IMAGE	15	8	100%		$15886990. \times 10^6$	1	15886990	
	RADAR IMAGE	25	10000	1%		$23830486. \times 10^6$	1	23830486	67519708.0×10^6
10	4 BAND VISIBLE	30	8	100%	TOTAL LAND	5295663×10^6	1	5295663*	
	2 BAND NEAR IR	40	8	100%	AREA 148 940 540	1489405×10^6	1	1489405*	
	1 BAND THERMAL IR	120	8	100%		82744×10^6	2	165488*	
	3 BAND STEREO IMAGE	15	8	100%		15886990×10^6	1	15886990*	
	RADAR IMAGE	25	10000	.1%		2383048×10^6	1	2383048	$(2404231. \times 10^6)$**
	4 BAND VISIBLE	15	8	.1%		21183×10^6	1	21183	$25241777. \times 10^6$

*DATA FOR OTHER REQUIREMENTS WILL SERVE THIS REQUIREMENT.

**ADDITIONAL DATA ONLY

OBSERVATION REQUIREMENT	TYPE MEASUREMENT	SPATIAL RESOLUTION IN METERS	QUANTIZATION LEVEL PER BAND	SAMPLE SIZE	AREAL EXTENT AND AREA IN $(KM)^2$	TOTAL BITS PER OBSERVATION	NUMBER OF OBSERVATIONS	TOTAL BITS PER YEAR $X10^6$	TOTAL BITS PER YEAR PER OBSERVATION REQUIREMENT
11	4 BAND VISIBLE	30	8	100%	TOTAL LAND	5295663×10^6	1	5295663	(5295663×10^6)**
	3 BAND STEREO IMAGE	15	8	100%	AREA 148 940 540	15886990×10^6	1	15886990*	21182653×10^6
12	4 BAND VISIBLE	30	8	100%	25% OF LAND	1323916×10^6	1	1323916*	
	2 BAND NEAR IR	40	8	100%	AREA 37 235 135	372351×10^6	1	372351*	
	1 BAND THERMAL IR	120	8	100%		20686×10^6	1	20686*	
	5 BAND PASSIVE MW	30KM	10	100%		2×10^6	30	62	
	2 BAND ACTIVE MW	1KM	10	100%		745×10^6	12	8936	
	4 BAND VISIBLE	30	8	10%		132391×10^6	10	1323910	
	2 BAND NEAR IR	40	8	10%		37235×10^6	10	372350	
	1 BAND THERMAL IR	120	8	10%		2069×10^6	10	20690	
	4 BAND VISIBLE	15	8	5%		264783×10^6	5	1323915	(15645625×10^6)**
	RADAR IMAGE	25	10000	.1%		595762×10^6	1	595762	17362578
13	5 BAND PASSIVE MW	100KM	72	100%	WHOLE EARTH	1836×10^6	1460	2680952	
	VERTICAL SOUNDER	100KM	64	100%	510 074 600	326×10^6	1460	476614	
	2 BAND NEAR IR	10KM	10	100%		1020×10^6	17520	17873013	
	UPPER ATMOSPHERE (4)	NA	10			100×10^6	365	36500	21067079×10^6**
14	5 BAND PASSIVE MW	30KM	8	100%	NORTH AMERICA	1.08×10^6	1460	1578	
	VERTICAL SOUNDER	10KM	60	50%	24 320 100	7.30×10^6	1460	10652	
	5 BAND NEAR IR	1KM	10	100%		1216.00×10^6	17520	21304407	
	5 BAND PASSIVE MW	30KM	8	100%	NORTH PACIFIC	3.68×10^6	1460	5386	
	2 BAND ACTIVE MW	1KM	8	100%	83 000 000	1328.00×10^6	1460	1938880	
	VERTICAL SOUNDER	30KM	60	100%		5.53×10^6	1460	8078	
	5 BAND NEAR IR	1KM	10	100%		41.5×10^6	17520	727080	23996061×10^6**
15	5 BAND NEAR IR	500	10	12.5%	NORTH AMERICA	668.8×10^6	8760	5858712	
	MET RADAR	500	1000	.5%	AND COASTAL	535.0×10^6	120	64205	
	VERTICAL SOUNDER	10KM	60	12.5%	AREAS 26 752 110	20.06×10^6	120	2407	
	5 BAND PASSIVE MW	10KM	8	12.5%		13.38×10^6	120	1605	
	2 BAND ACTIVE MW	1KM	8	12.5%		53.05×10^6	120	6420	5933349×10^6**

*DATA FOR OTHER REQUIREMENTS WILL SERVE THIS REQUIREMENT.

**ADDITIONAL DATA ONLY

OBSERVATION REQUIREMENT	TYPE MEASUREMENT	SPATIAL RESOLUTION IN METERS	QUANTIZATION LEVEL PER BAND	SAMPLE SIZE	AREAL EXTENT AND AREA IN $(KM)^2$	TOTAL BITS PER OBSERVATION	NUMBER OF OBSERVATIONS	TOTAL BITS PER YEAR $X10^6$	TOTAL BITS PER YEAR PER OBSERVATION REQUIREMENT
16	5 BAND PASSIVE MW	30KM	8	100%	WORLD AGRICULTURE 75 000 000	3.33×10^6	250	833	
	2 BAND ACTIVE MW	1KM	8	10%		120.00×10^6	250	30000	
	5 NEAR IR	1KM	10	100%		3750.00×10^6	250	937500	
	1 BAND THERMAL IR	120	8	1%		416.67×10^6	250	104167	
	MET RADAR	500	1000	1%		30000.00×10^6	182	5460000	6532500×10^6**
17	5 BAND NEAR IR	30KM	10	100%	TOTAL OCEAN 361 134 060	20.06×10^6	1460	29292*	
	4 BAND VISIBLE	30	8	10%		1284032.1×10^6	4	5136128	
	5 BAND PASSIVE MW	30KM	8	100%		16.05×10^6	1460	23434	
	2 BAND ACTIVE MW	10KM	8	100%		57.78×10^6	1460	84361	
	VERTICAL SOUNDER	100KM	64	100%		$.23 \times 10^6$	1460	337*	
	ALTITUDE	1KM	350	100%		12639.69×10^6	182	2300424	65325796×10^6**
	RADAR IMAGE	25	10000	1%		57781449×10^6	1	57781449	65355425×10^6
18	5 BAND NEAR IR	30KM	10	100%	TOTAL OCEAN 361 134 060	20.06×10^6	1460	29292*	
	1 BAND THERMAL IR	120	8	.1%		200630.03×10^6	121	24276233	
	5 BAND PASSIVE MW	30KM	8	100%		16.05×10^6	1460	23434*	
	2 BAND ACTIVE MW	10KM	8	100%		57.78×10^6	1460	84361*	24276233×10^6**
	ALTITUDE	1KM	350	100%		$.23 \times 10^6$	1460	337*	24413657×10^6
19	5 BAND NEAR IR	10KM	10	100%	POLAR REGIONS 92 000 000	46.00×10^6	52	2392	
	5 BAND PASSIVE MW	30KM	8	100%		4.09×10^6	52	212	
	2 BAND ACTIVE MW	10KM	8	100%		14.72×10^6	52	765	
	ALTITUDE	1KM	350	100%		32200.00×10^6	52	1674400*	
	1 BAND THERMAL IR	120	8	100%		5111.10×10^6	52	265777	1793315×10^6**
	RADAR IMAGE	25	10000	1%		1472000.00×10^6	12	17664000	3467715